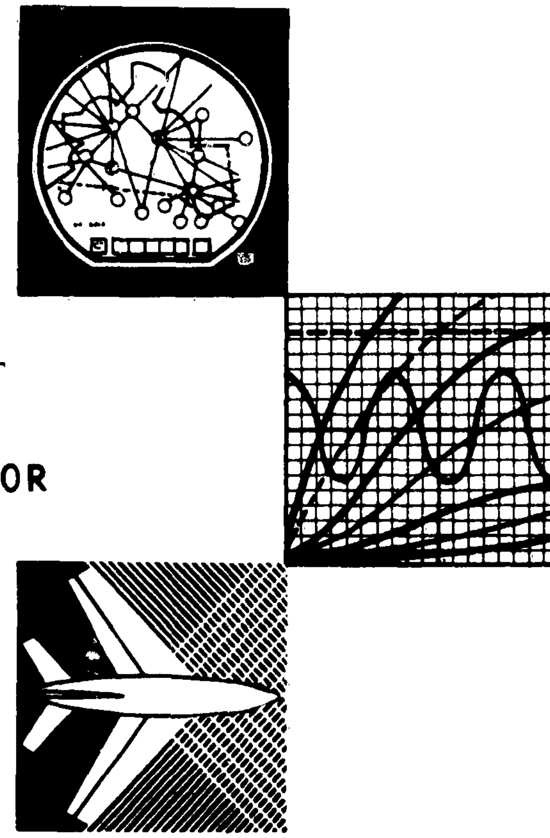


FINAL REPORT

Project No. 101-910R

INVESTIGATION OF CHARACTERISTICS OF THE PENTAGONAL TOWER CAB

FEBRUARY 1963

FEDERAL AVIATION AGENCY
Systems Research & Development Service
RESEARCH DIVISION
Atlantic City, New Jersey

FINAL REPORT

INVESTIGATION OF CHARACTERISTICS OF THE PENTAGONAL TOWER CAB

Project No. 101-910R

Prepared by:

T. H. Green

February 1963

This report has been approved for general distribution.

Joseph D. Blatt
Director, Systems Research
and Development Service
Federal Aviation Agency

Research Division
National Aviation Facilities Experimental Center
Atlantic City, New Jersey

Research Division, Systems Research and Development Service, Federal Aviation Agency, Atlantic City, N.J.
INVESTIGATION OF CHARACTERISTICS OF THE PENTAGONAL TOWER CAB, by T. H. Green, December, 1962, 74 pp., plus 25 illus., Final Report
(Project No. 101-910R)

ABSTRACT

A proposed pentagonal tower cab is investigated with particular attention being given to relations between several design features and visibility. While shape itself was not studied as a design alternative, certain findings on the effects of shape of the cab, as well as on slope of glass windows, height of ceiling, interior equipment, and other dimensions, are presented. Concurrent analytic, physical, and operational approaches were utilized. Based on progress to date, conclusions and suggestions for future investigation are stated.

An automated window washing system is proposed, and results of preliminary tests of the system are reported.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

The author wishes to acknowledge the contribution of the following individuals whose efforts contributed significantly to this project:

Dr. R. K. McKelvey, Chief, Human Factors Research Branch, Research Division, SRDS, FAA

Dr. E. P. Buckley, psychologist, Franklin Institute Laboratories

Mr. L. E. Paul, psychologist, Research Division, SRDS, FAA

Mr. J. R. Vander Veer, mathematician, Research Division, SRDS, FAA

Mr. D. C. Michel, architect-engineer, Supporting Services Division, SRDS, FAA

Mr. J. C. Cox, photographer, Technical Services Division, SRDS, FAA

Turco Products Incorporated, Los Angeles, California, and their local field service representative, Mr. H. C. Mason, contributed both advice and equipment that expedited the window washing experiments.

Among the organizations at NAFEC that extended themselves to make significant contributions were personnel of the:

Plant Engineering Branch, Supporting Services Division

ATC Laboratories Section, Technical Services Division

Engineering Support Section, Technical Services Division

Photographic Unit, Technical Services Division

INTRODUCTION

Purpose

The purpose of this report is to provide information on certain operational utility aspects of a proposed tower cab design that the Federal Aviation Agency is now considering.

Several studies have been made of tower cab design but none of these has provided an empirical basis for comparing the merits of one design with another. Consequently, the steps used in this investigation were:

1. Reexamine the operational purpose of the air traffic control tower cab.

2. Determine a list of design elements that might affect the operational purpose of the tower cab and select those which might be considered as basic to the design.

3. Gather data on the effects of these basic elements, as they were found in several operational cab designs, and compare with the proposed design.

Visibility Design Consideration

A tower cab has one functional purpose -- to provide the working space required for the air traffic control specialists to monitor visually and to control the aircraft traffic in the air near the airport and on the airport surface. The space provided must also house the communication equipment required to perform the control aspect of the controller's work.

Although there are several hundred air traffic control tower cabs in the United States, it seems that no two are exactly alike. Ideally, tower cabs are located at prominent elevated locations from which the operating personnel can obtain a 360 degree, unobstructed view of the airport and its surrounding airspace. The location and elevation vary with the local airport conditions, although they all conform to siting procedures established by the FAA. The shape, dimensions and features also have been subject to considerable variation. Therefore, it was not possible to appraise the proposed design against a "typical" tower cab. Rather it was necessary to determine those things that influenced the primary function of the tower cab, visual control of

terminal traffic, and measure their effects in several widely used cab designs.

In all tower cabs visibility is determined by certain physical factors. The floor to ceiling height, the window sill height, and the slope of the sides all limit the upward and downward angles of visibility. The console height and cross sectional width influence the controller's position relative to the glass and affect both the upward and downward angles of visibility. The number and dimensions of roof supports and window mullions interfere with and reduce unobstructed peripheral visibility. In addition to these physical factors, the glare and reflections that exist at various times also have a definite and detrimental effect.

The following is a list of physical elements that relate to visibility and that should be considered in a tower cab design:

1. Geometrical shape of the cab.
2. Slope of the glass.
3. Floor to ceiling height.
4. Ceiling material and design.
5. Floor material and design.
6. Types of glass.
7. Tint of glass.
8. Interior furnishings and equipment.
9. Color of interior.

This report deals only with a particular, proposed tower cab design. Considerations of tower cab location and elevation will be mentioned but were not investigated thoroughly.

The Proposed Design

In very general terms, the tower cab design under investigation is a regular pentagonal shape (five equal length sides). The total floor area is 400 square feet. The ceiling to floor height is approximately ten feet. The sides flare outward at an angle of 12 1/2 degrees. Each side contains two panes of single thickness, untinted, polished plate glass with a total surface area of approximately 140 square feet.

METHOD OF EVALUATION

Section 2

The Test Environment

Full Scale Mock-Up

To facilitate this investigation a full sized plywood and glass mock-up of the proposed tower cab design was built at NAFEC and placed on an eighty foot tower. The tower was located within several hundred feet of both the operational control tower and the municipal terminal at what was considered to be a possible operational site.

Like the proposed cab design, the mock-up has a regular pentagonal geometrical configuration and a floor area of 400 square feet. The sides flare outward at an unbroken angle of 12/12 degrees; the floor to ceiling height measures ten feet three inches (10' - 3"); and the floor to window sill height is approximately three feet. The ceiling is flat and made of an untextured sheetrock material. The floor is flat and made of painted plywood. The interior of the cab is painted in several shades of non-reflecting, blueblack paint.

The mock-up is fitted with 1/2" single thickness, untinted plate glass. Each side contains approximately 140 square feet of glass area in two equal sized panes. Each pane is supported on three sides in the conventional manner. The fourth, or inclined edge, is beveled and mated to the adjacent pane without the use of a metal window mullion. The joint is sealed with a pliable expoxy mastic. Hence, there are a total of five combined window and roof supports.

A beaverboard mock-up of the type T-2 console was placed on all sides of the tower cab.

Optical Miniatures

A review of the principles of optics indicated that like reflection patterns could be obtained with the use of a miniature or scaled model of the mock-up deisgn. Four such miniatures were built, their dimensions being 1/12 full size. Represented were three geometrical shapes (square, pentagon, and irregular octagon) and three glass slopes (12 1/2°, 15°, and 17 1/2°). In addition, one miniature was provided with several replaceable ceiling designs.

It was possible to vary the ceiling to floor height in one of the miniatures. The use of models permitted a greater amount of data to be collected in a far shorter time and with a 90% saving in proposed contract funds.

In order to validate the optical miniature concept, photographs were taken from inside the full sized cab and from inside its optical miniature. Because of the uncertainties and vagaries of sky brightness, additional work with the optical miniatures was done indoors in a controlled lighting environment.* Figure 2-1 is a photograph of reflected images taken from inside the full size tower cab, and Figure 2-2 is a photograph of reflected images taken from inside the optical miniature of the same cab design. Both were lighted by the afternoon sun. Figure 2-3 is a photograph of the results of an early experiment using the optical miniature of the proposed cab design illuminated by the controlled lighting environment.

In addition to showing the reflection patterns that characterize each shape of tower cab, an attempt was made to record photographically the loss of discrimination that results when aircraft are viewed in certain reflections. Aircraft silhouettes of black, aluminum, dark gray, lighter gray, and white were placed on a light gray background. The photographs were taken from the geometric center of each optical miniature. Camera setting, lighting, and camera height were not changed during a series of photographs. The models were lighted by an evenly diffused, controlled lighting arrangement. Figures 2-4 through 2-10 are photographs of the reflected images that occur in a corner of each model.

APPROACH

The investigation of the functional suitability of the cab design was pursued concurrently with three approaches: 1. An analytical approach, 2. A physical approach, and 3. An operational approach.

Analytic

In the beginning, several nationally recognized organizations and agencies were contacted. The visibility problem in tower cabs was outlined with the hope that we would be put in touch with completed or on-going work. No projects were found.

* One design of this environment was proposed and implemented by Mr. J. Cox, a member of the photographic staff at NAFEC.

Another effort was directed at utilizing the knowledge of a consultant illumination engineer familiar with airport problems. A contract was initiated with L. W. Hornfeck, Incorporated, Pittsburgh, Pennsylvania, and a report of their analysis of the glare problem was prepared. This consultant's report is presented as Appendix C to this report. Extensive use of Mr. Hornfeck's work was made in the preparation of this report. The project staff also carried out a rational analysis of functional requirements and design considerations.

Physical

Both the full sized mock-up of the proposed design and a series of scaled miniature tower cabs of varying designs were used to demonstrate the variables identified in the analytic approach. The primary tool was photography. Pictures were taken from inside the various tower models to demonstrate the visual effects of concern.

Operational

By means of a questionnaire survey, opinions relevant to the basic elements of tower design were obtained from a representative sample of controllers who possessed recent and diversified tower experience. Controller opinion was collected on two major questions; (1) design elements that were considered to be of prime importance to a controller, and (2) desirability of the arrangement of those elements in the proposed cab design. Controller opinion on the shape of cab, location of the control tower, orientation of the cab with the active runway, and controller position in the cab was also obtained.

Before responding to these questionnaires, all participating controllers were given a systematic exposure to the tower cab mock-up.

In a supplementary effort, experienced controllers were sent to a selection of high density airports to observe the visual monitoring activities of the local controller, especially with respect to the upward viewing angle.

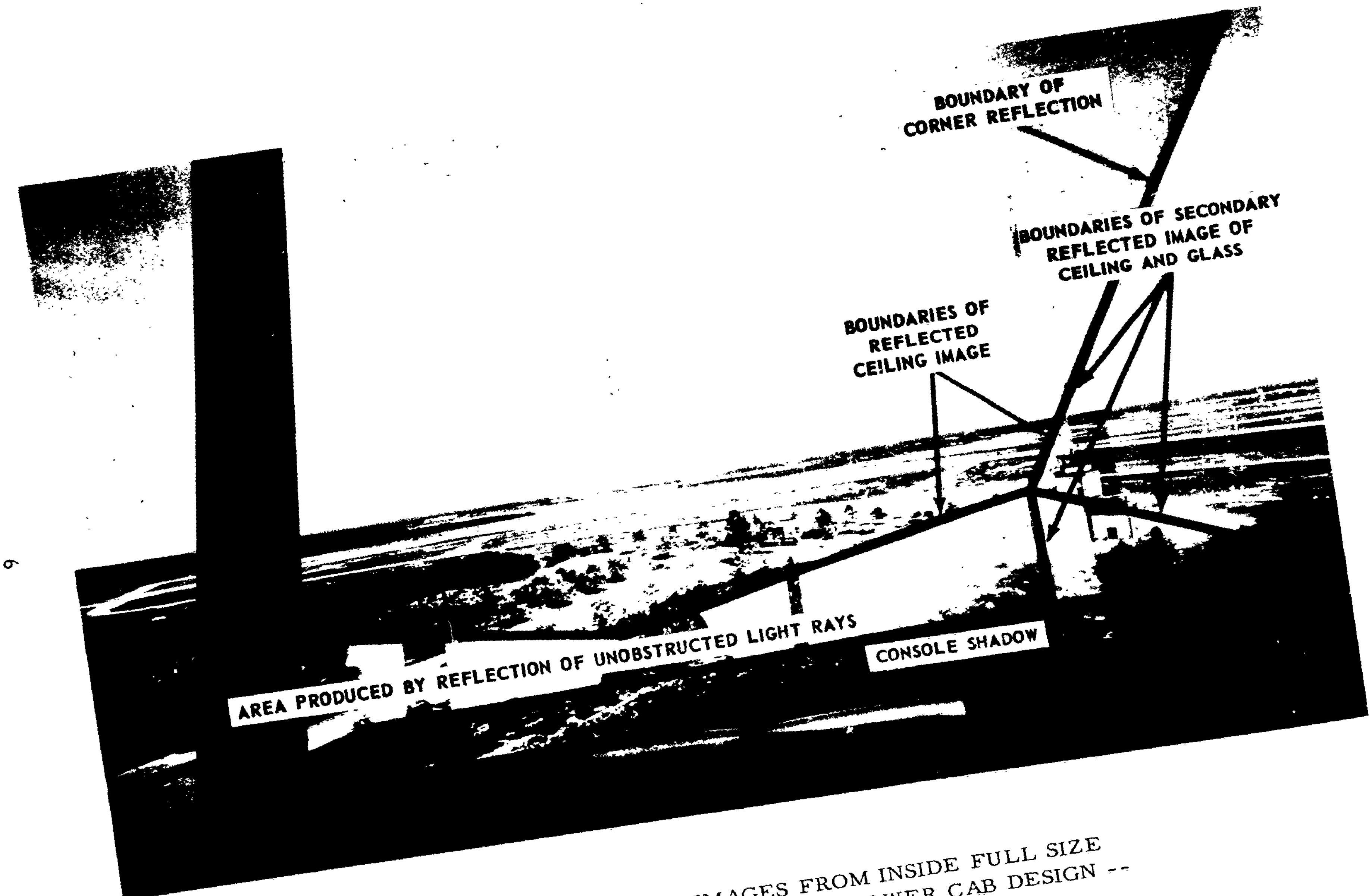


FIG. 2 - 1 REFLECTED IMAGES FROM INSIDE FULL SIZE MOCK-UP OF PROPOSED TOWER CAB DESIGN -- LIGHTED BY AFTERNOON SUN

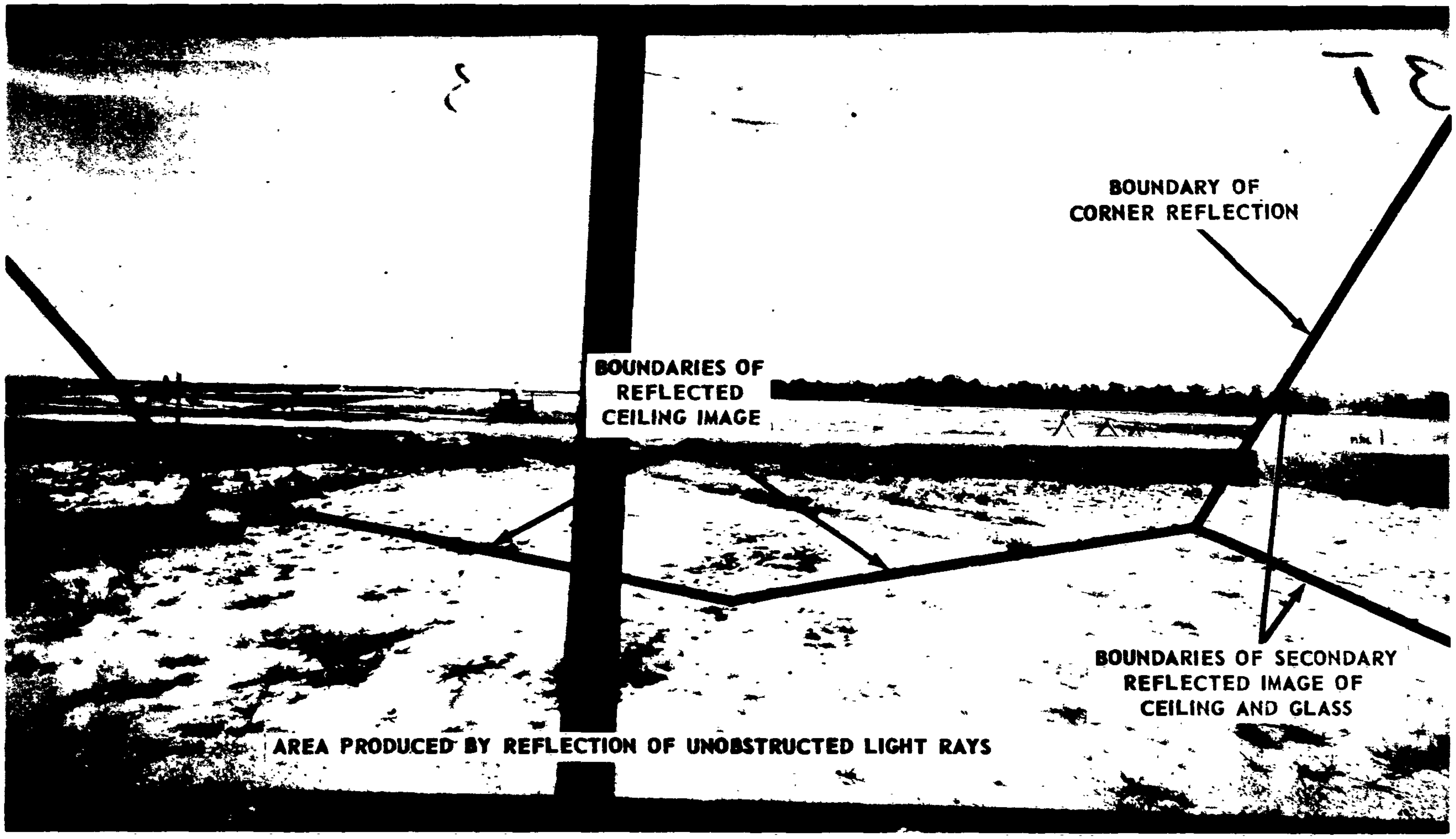


FIG. 2 - 2 REFLECTED IMAGES FROM INSIDE THE "OPTICAL MINIATURE" OF PROPOSED TOWER CAB DESIGN -- MODEL SITUATED ON 5 FOOT HIGH STAND AND LIGHTED BY AFTERNOON SUN

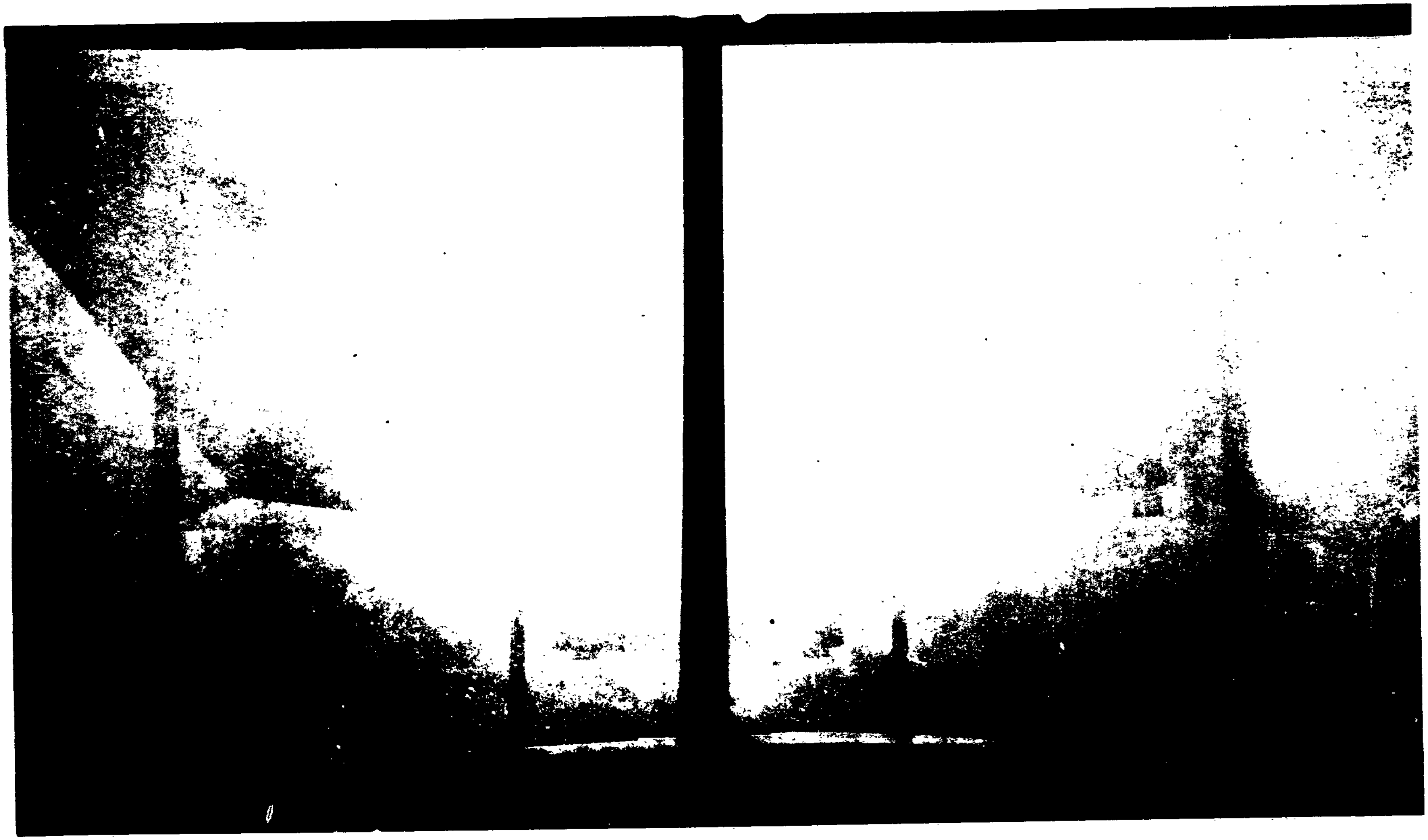


FIG. 2 - 3 RESULTS OF AN EARLY EXPERIMENT USING "OPTICAL MINIATURES" LIGHTED IN A CONTROLLED ENVIRONMENT

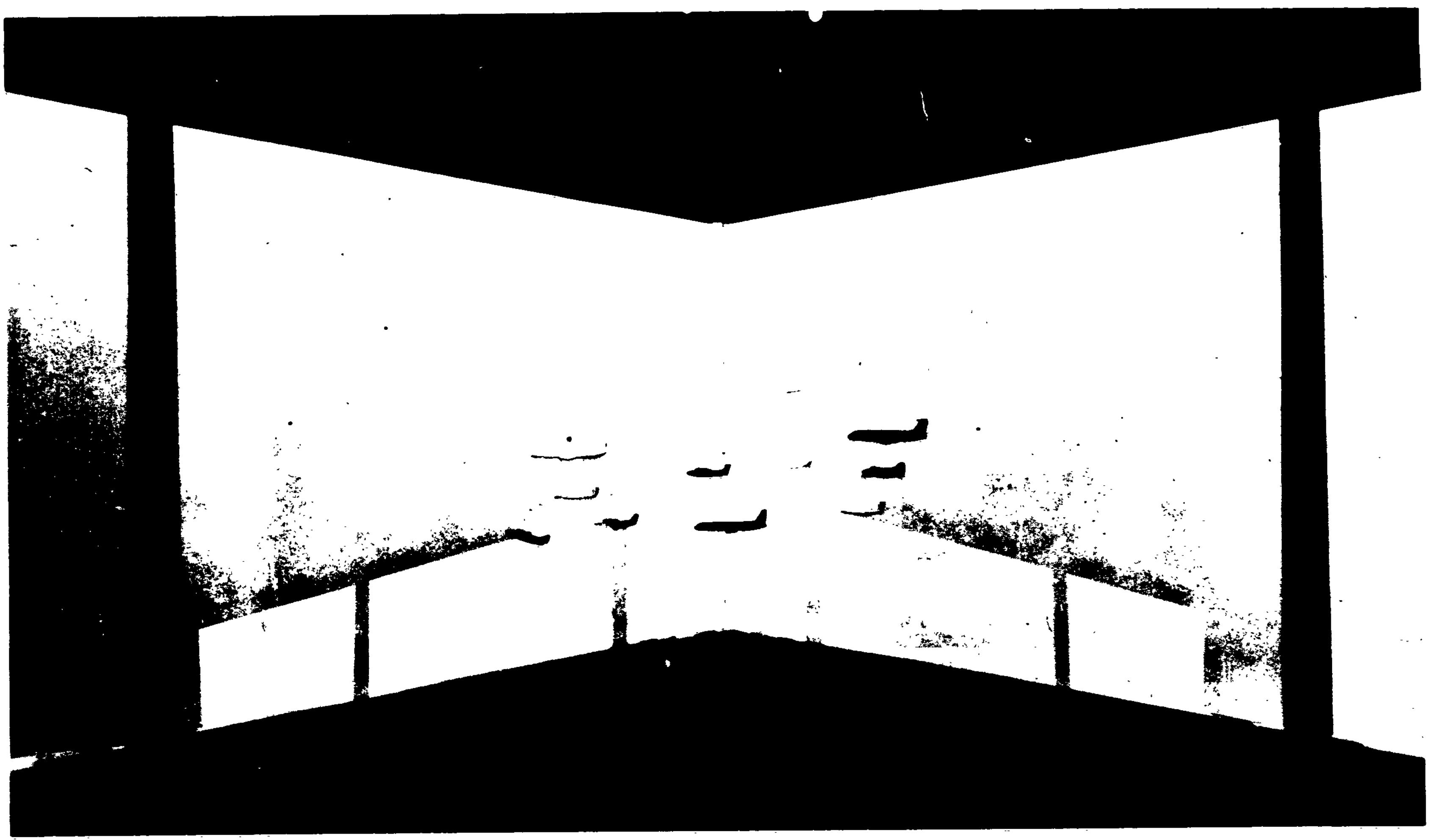


FIG. 2 - 4 REFLECTED IMAGES IN AN "OPTICAL MINATURE" OF A PENTAGONAL CAB -- 12 1/2° GLASS SLOPE, 10 FOOT FLOOR TO CEILING HEIGHT

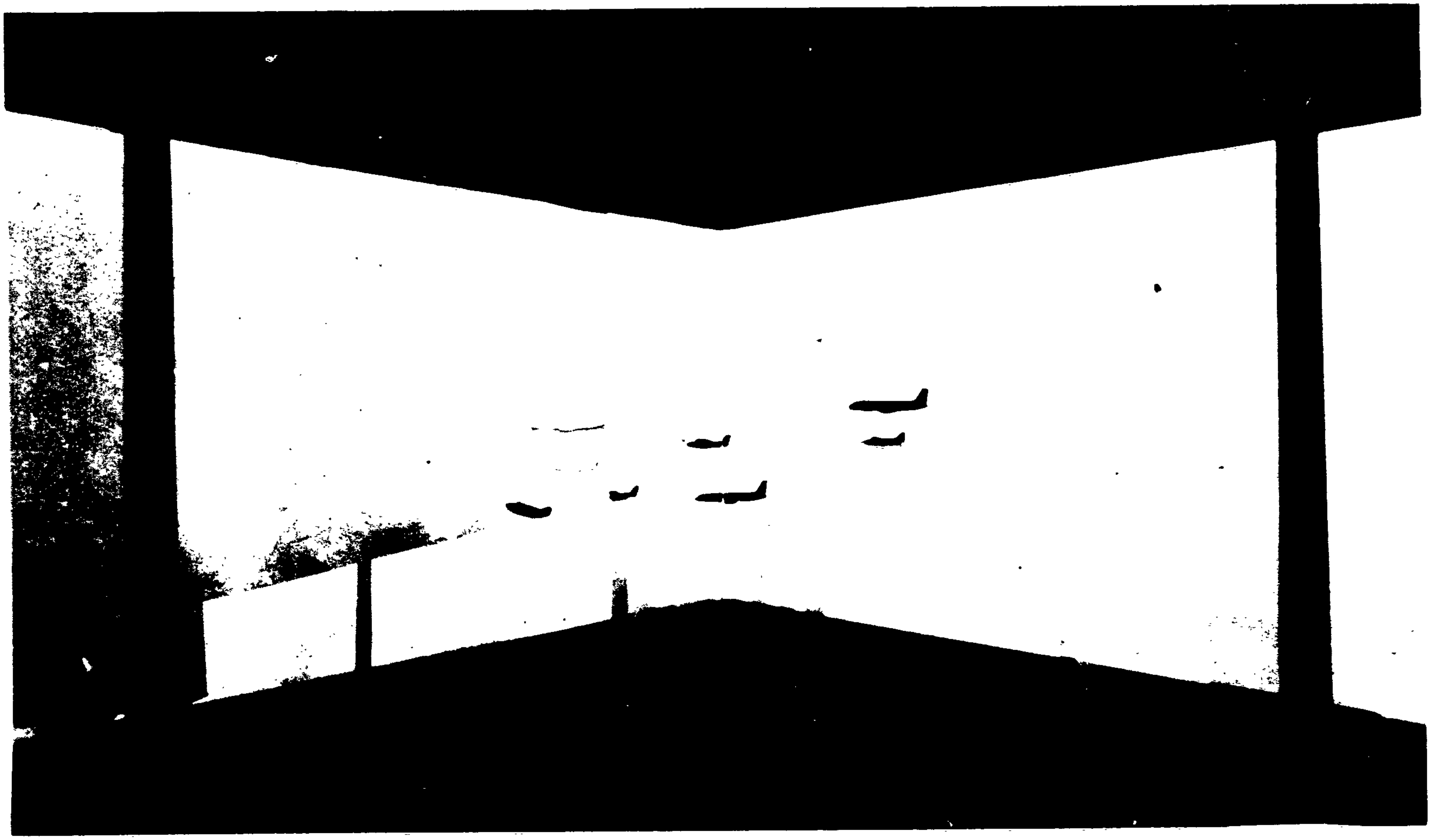


FIG. 2 - 5 REFLECTED IMAGES IN AN "OPTICAL MINIATURE" OF A PENTAGONAL CAB -- 12 1/2° GLASS SLOPE, 9 FOOT FLOOR TO CEILING HEIGHT

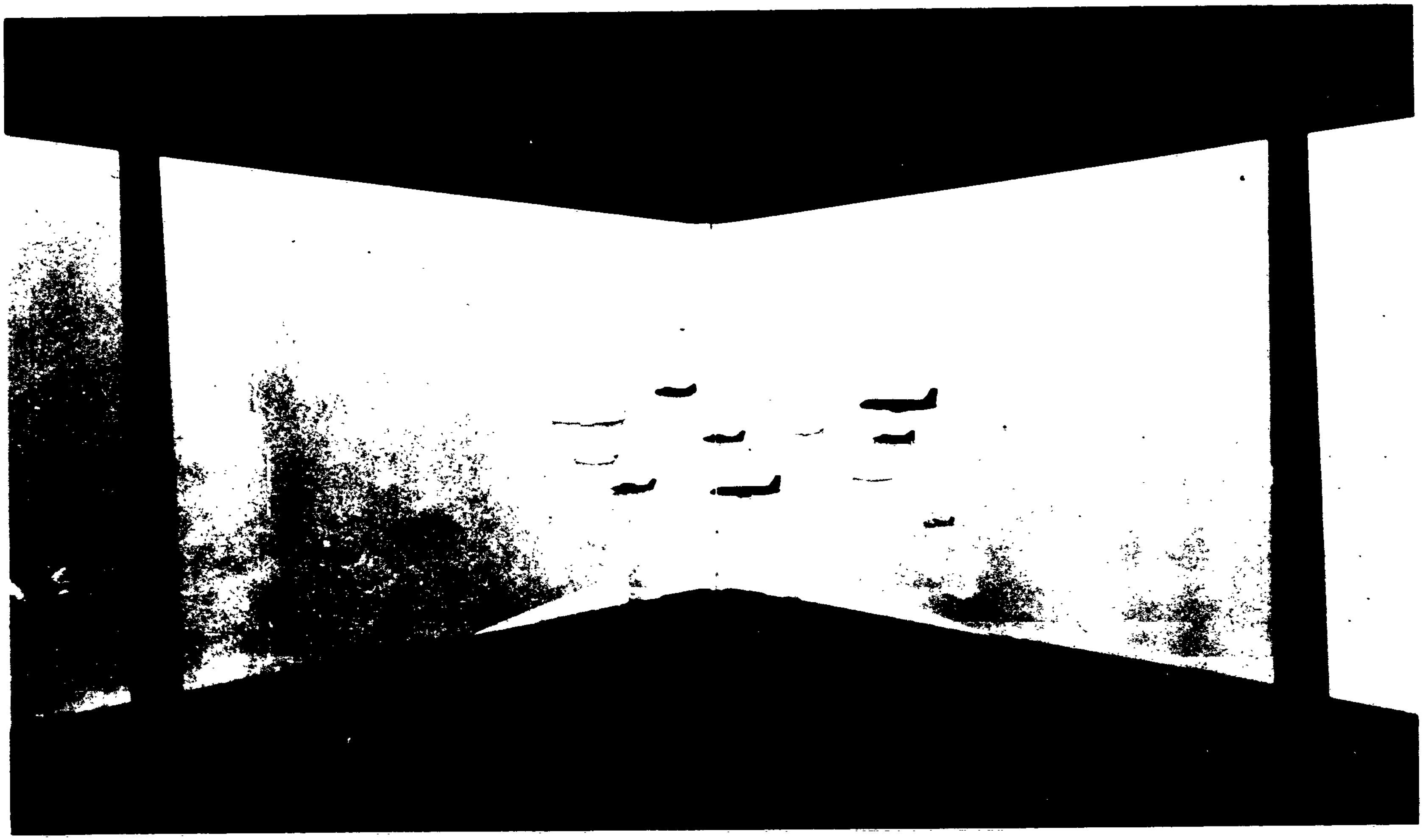


FIG. 2 - 6 REFLECTED IMAGES IN AN "OPTICAL MINIATURE" OF A PENTAGONAL CAB -- 17 1/2° GLASS SLOPE, 10 FOOT FLOOR TO CEILING HEIGHT

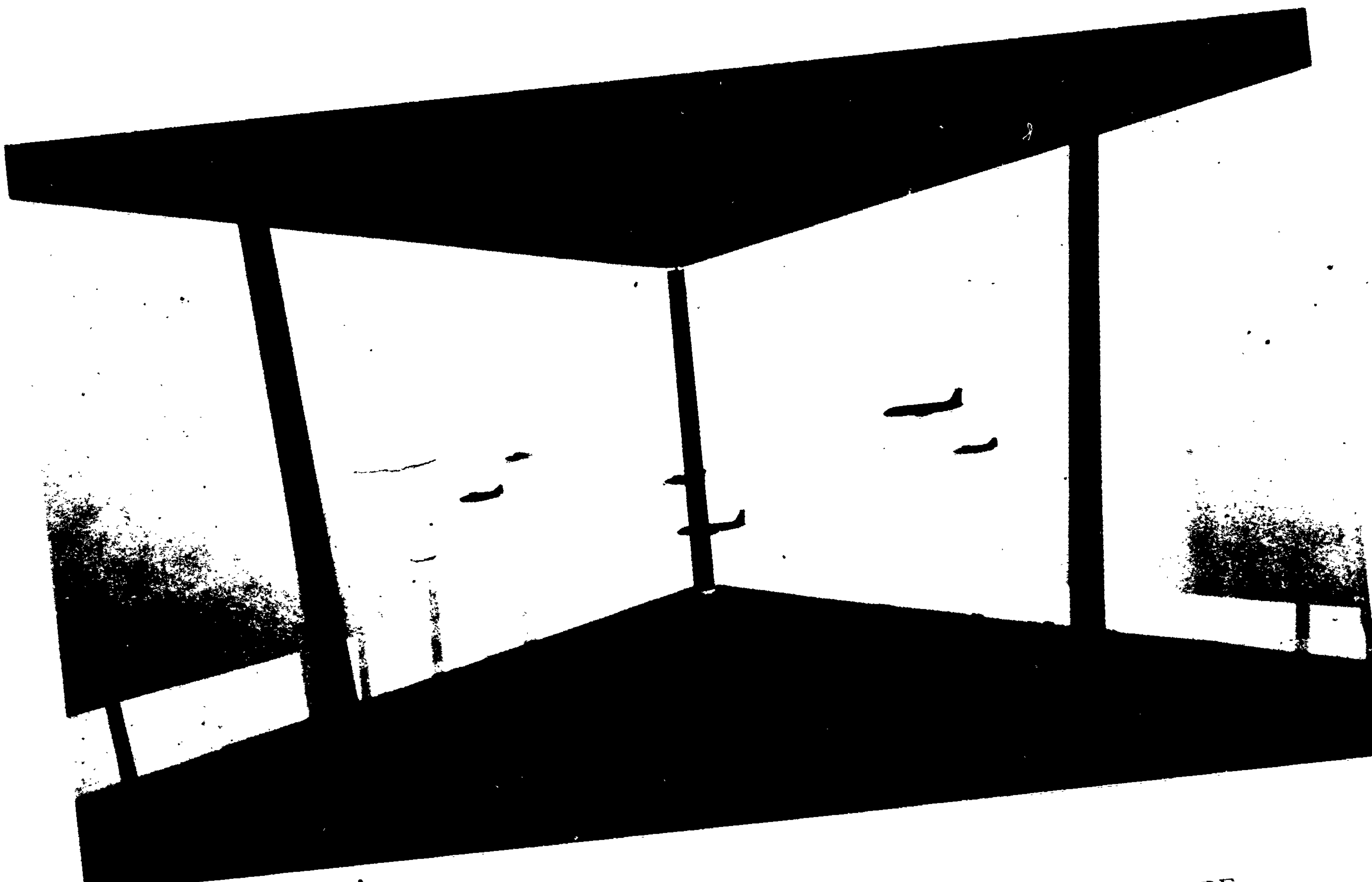


FIG. 2 - 7 REFLECTED IMAGES IN AN "OPTICAL MINIATURE" OF A SQUARE CAB -- CORNER COLUMN IN PLACE -- 15° GLASS SLOPE, 10 FOOT FLOOR TO CEILING HEIGHT

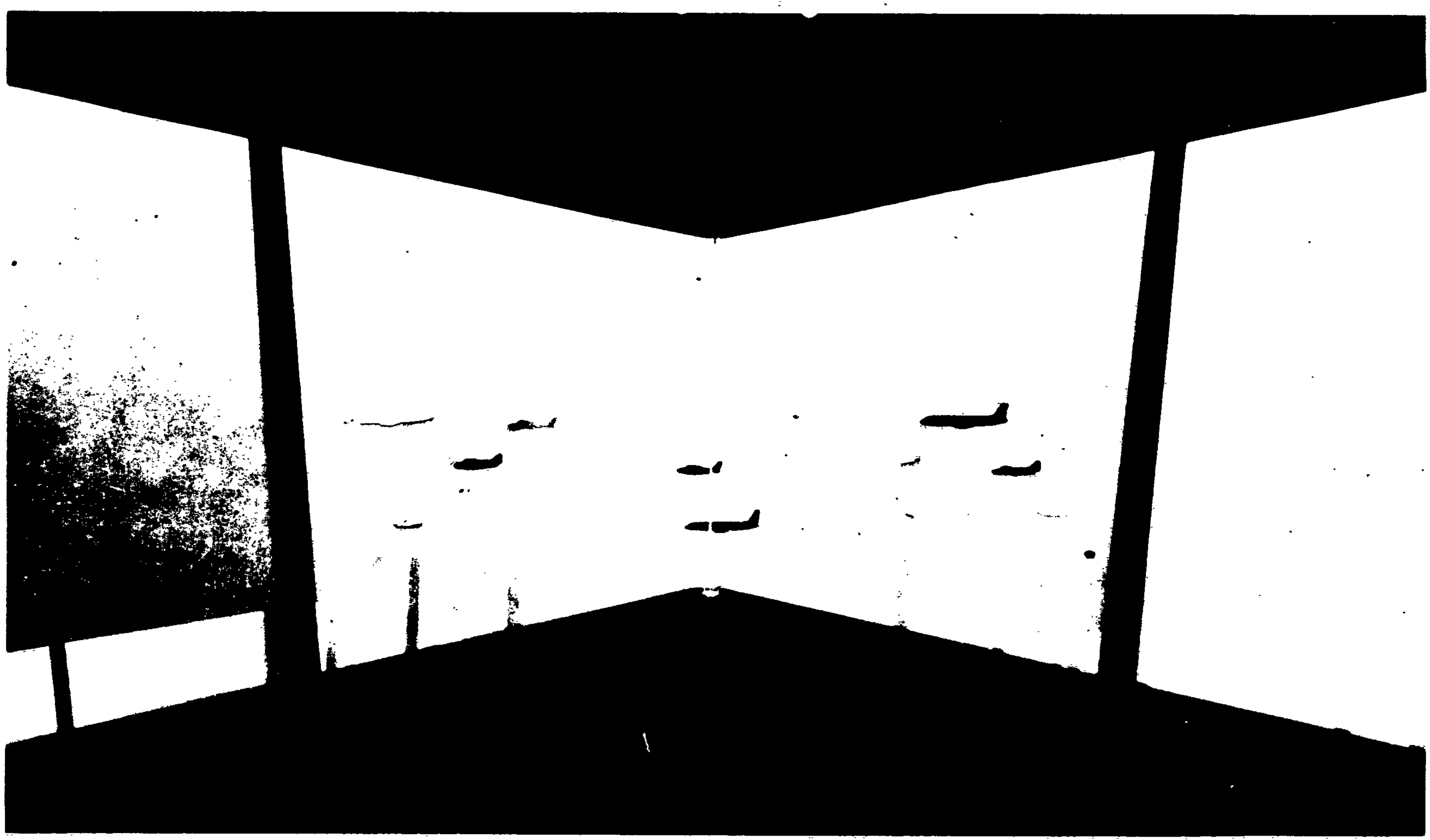


FIG. 2 - 8 REFLECTED IMAGES IN AN "OPTICAL MINIATURE" OF A SQUARE CAB -- CORNER COLUMN REMOVED -- 15° GLASS SLOPE, 10 FOOT FLOOR TO CEILING HEIGHT

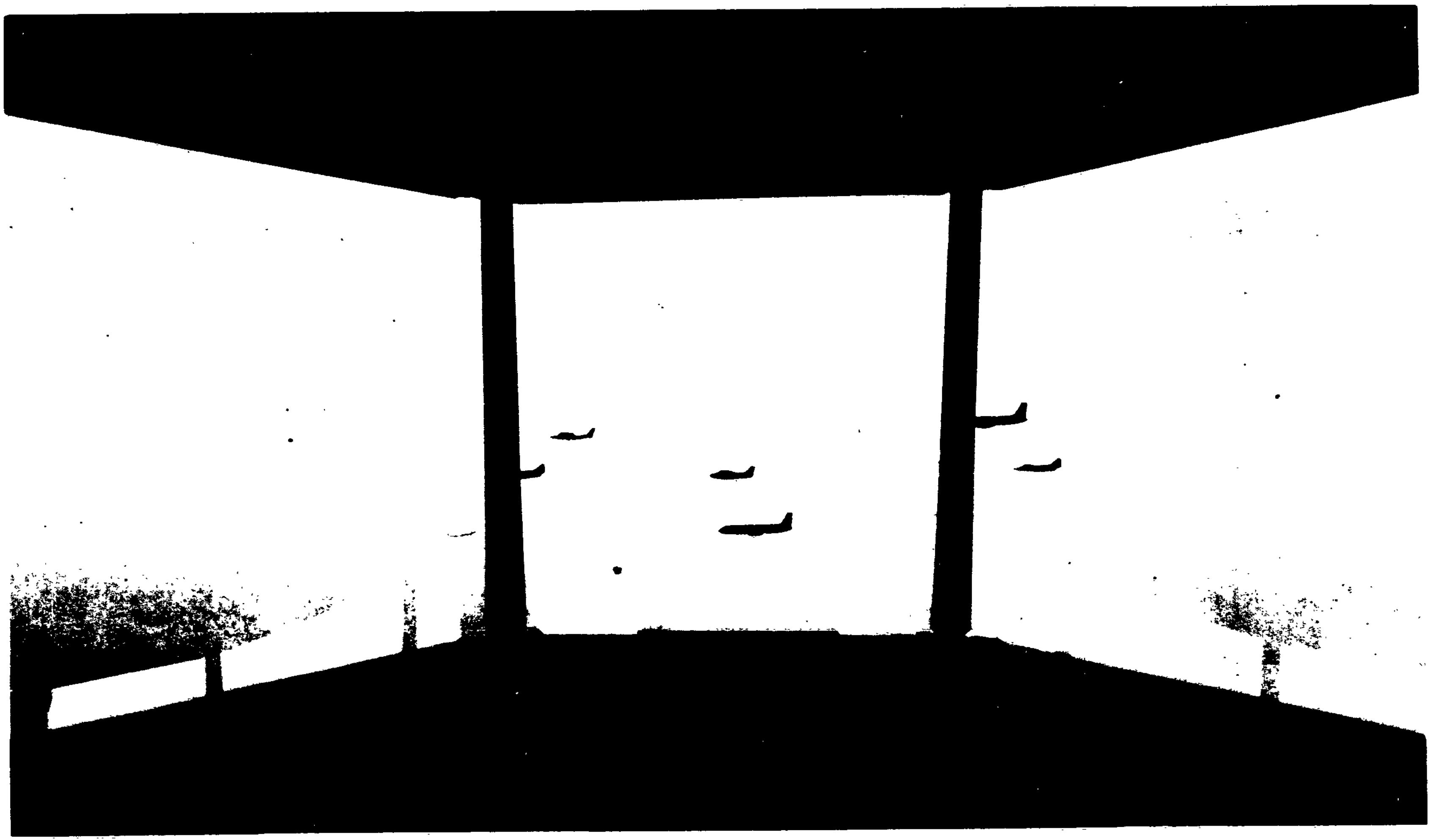


FIG. 2 - 9 REFLECTED IMAGES IN AN "OPTICAL MINIATURE" OF AN IRREGULAR OCTAGONAL CAB (T.S.O. DESIGN) -- CORNER COLUMN IN PLACE -- 15° GLASS SLOPE, 10 FOOT FLOOR TO CEILING HEIGHT

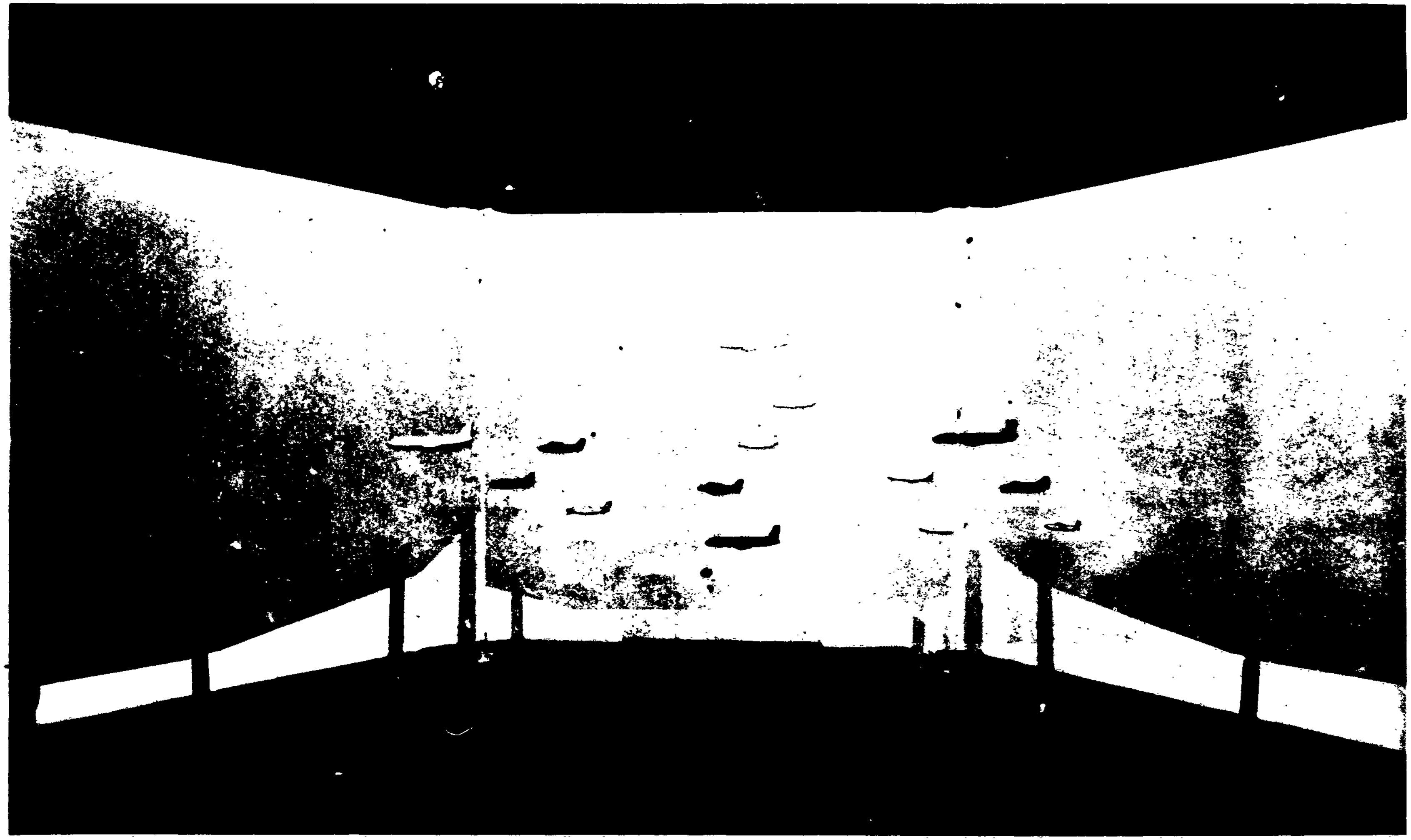


FIG. 2 - 10 REFLECTED IMAGES IN AN "OPTICAL MINIATURE" OF AN IRREGULAR OCTAGONAL CAB (T.S.O. DESIGN) -- CORNER COLUMNS REMOVED -- 15^{o} GLASS SLOPE, 10 FOOT FLOOR TO CEILING HEIGHT

FINDINGS

Section 3

Summary of Critical Physical Dimensions and Considerations

The following have been confirmed as critical in the cab design with respect to visual task implication: geometry, slope of glass, ceiling material and design, floor to ceiling height, glass, interior paint color, and interior furnishings and equipment. The geometric configurations, the ceiling height, slope of glass, etc. limit upward and downward visibility. In addition, controller visibility is affected by the presence and location of reflected images on the tower cab glass. Typical reflected images are shown in Figure 2-1, a photograph taken from the mock-up of the proposed tower cab design.

Reflected images change with the position of the observer, the height of the observer's eyes, and the sky brightness. Not all males are of the same height, however 95% of their eyes range between heights of 61 and 71 inches. Hence, an average eye height of 66 inches was used in the mathematical formulas developed for this report.

For the purpose of this report, we will not consider the effects produced by light entering the cab at night. These light sources are either of a transitory nature (lights on taxiing aircraft) or are subject to control by the application of established illuminating engineering techniques (repositioning glaring ramp lights). The interior illumination of the tower cab will be discussed in connection with interior furnishing and equipment.

A more detailed analysis of each of these factors follows.

Geometrical Shape

The Geometry of the cab determines the magnitude of the included angles between adjacent sides. This limited study of geometric shapes indicates, in turn, that the magnitude of the included angle has an inverse relationship to the area of corner reflections. Additional work is required before this indication can be substantiated. A mathematical formula developed by Mr. J. R. Vander Veer, a mathematician in the Research Division, expresses this relationship. The complete mathematical expression is presented in the Appendix.

The formula indicates that for a particular situation in which only the included angle is varied the areas of corner reflection are as follows:

Square Cab	90° Angle	795 sq. in. area
Pentagonal Cab	108° Angle	475 sq. in. area
Hexagonal Cab	120° Angle	None

Examination of the photographs indicates that the area of corner reflection is decreased significantly as the geometric shape changes from square to pentagonal. Also, it would appear from examination of the photographs taken in the pentagonal cabs that a secondary reflection of an adjacent corner and ceiling is introduced into the area of corner reflection. This secondary reflection appears to reduce the brightness of the corner area. A hexagonal tower cab model was not made for this project.

The geometric shape also limits the angles of upward and downward visibility from the cab. Results of a geometric analysis performed with three shapes is shown in Table 3-1 on the following page.

Slope of Glass

The glass in a tower cab is inclined at some angle to direct the refelction of light rays to some light diffusing and absorbing surface such as the floor or ceiling. If the glass were vertical, the reflected rays would bound and rebound between opposite panes of glass producing a myriad of reflected images. If the glass were sloped so that the floor were larger than the ceiling, a greater proportion of the rays would be directed to the floor. Since the floor is used also as a working surface, its ability to absorb and diffuse light is considerably less than that of the uncluttered ceiling.

When other design elements such as geometric shape, floor to ceiling height, etc. are held constant, an increase in glass slope increases the depth of the shielded area at the top of the glass, reduces the height of the bright area at the bottom of the glass, and slightly reduces the area of corner reflection. The bright area above the window sill results from light rays that traverse the cab without impinging on a non-reflecting surface. The vertical height of the reflection in a pentagonal cab, as seen by an observer standing 28 inches to the left of a corner angle, is shown in Table 3-2 on page 19. The corner reflection area as a function of glass slope is shown in Table 3-3 which is also located on page 19.

Table 3-1

UPWARD AND DOWNWARD VISIBILITY ANGLES

FOR SEVERAL CAB SHAPES

	CAB SHAPES					
Bearing Angle from Observer's Position	SQUARE		PENTAGON		IRREGULAR OCTAGON	
	Downward Visibility Angle	Upward Visibility Angle	Downward Visibility Angle	Upward Visibility Angle	Downward Visibility Angle	Upward Visibility Angle
0	18.0°	24.6°	25.5°	33.1°	25.5°	33.1°
20	22.6°	30.1°	24.3°	30.8°	24.0°	31.0°
40	24.8°	32.7°	23.1°	30.5°	19.6°	26.0°
60	24.2°	32.0°	22.2°	29.7°	14.0°	20.5°
80	20.7°	28.0°	19.3°	26.1°	10.4°	17.6°
100	14.6°	20.0°	13.5°	19.4°	9.1°	17.0°
120	7.9°	15.0°	9.5°	17.0°	8.1°	15.0°
140	8.0°	15.5°	8.2°	16.0°	7.0°	14.0°
160	7.4°	14.3°	7.7°	14.6°	7.5°	14.5°
180	5.6°	11.3°	7.0°	13.6°	8.2°	15.4°
200	7.4°	14.3°	7.7°	14.6°	8.9°	16.0°
220	8.0°	15.5°	8.2°	16.0°	12.2°	18.2°
240	7.9°	15.0°	9.5°	17.0°	16.0°	24.2°
260	14.6°	20.0°	13.5°	19.4°	18.3°	26.6°
280	20.7°	28.0°	19.3°	26.1°	19.5°	26.7°
300	24.2°	32.0°	22.2°	29.7°	22.5°	30.2°
320	24.8°	32.7°	23.1°	30.5°	23.4°	30.8°
340	22.6°	30.1°	24.3°	30.8°	24.0°	31.0°

Table 3-2

VERTICAL HEIGHT OF REFLECTIONS FROM A PENTAGONAL CAB AS A FUNCTION OF GLASS SLOPE

Slope of Glass	12 1/2°	15°	17 1/2°	20°
Total Vertical Floor to Ceiling Height	120 in.	120 in.	120 in.	120 in.
Vertical Height of Reflection	58.7 in.	55.2 in.	51.5 in.	47.6 in.
Vertical Height of Glass Sill	36 in.	36 in.	36 in.	36 in.
Vertical Height of Reflection Above Glass Sill	22.7 in.	19.2 in.	15.5 in.	11.6 in.
Percent Reduction	-	15%	33%	49%

Table 3-3

CORNER REFLECTION AREA FROM A PENTAGONAL CAB AS A FUNCTION OF GLASS SLOPE

Slope of Glass	12 1/2°	15°	17 1/2°	20°
Total Area of Corner Reflection	499.3 sq. in.	475.8 sq. in.	460.6 sq. in.	377.2 sq. in.
Percent Reduction	-	4.5%	8%	24.6%
Horizontal Distance Between Reflection's Inflection Points	62.18 in.	58.03 in.	55.45 in.	48.70 in.
Vertical Height of Reflection's Inflection Point Above Glass Sill	9.09 in.	8.97 in.	8.90 in.	7.81 in.

As the slope of the windows is increased, however, the angle of upward visibility is decreased. The values for a pentagonal cab are presented in Table 3-4.

TABLE 3-4

MAXIMUM ANGLES OF VISIBILITY FROM A PENTAGONAL CAB AS A FUNCTION OF GLASS SLOPE

Slope of Glass	12 1/2°	15°	17 1/2°	20°
Maximum Angle of Visibility Upward	35.5°	32.9°	31.8°	31.5°
Maximum Angle of Visibility Downward	25.7°	25.7°	25.7°	25.7°

The angles of upward and downward visibility at selected bearing angles for pentagonal tower cabs are presented in Figures 3-1 through Figures 3-3, located at the end of this section.

Ceiling Material, Design and Color

Light rays that impinge on the ceiling are reflected from the ground cover surrounding the tower or from the floor, consoles, and glass in the cab. The primary function of the ceiling should be to diffuse and absorb these reflected rays. A ceiling composed of a roughened, unpatterned material, with a color of low reflectance value, is best suited for this purpose. Although it is desirable to use the ceiling area as an acoustical damping surface, the use of materials that contain perforations and ridges is not desirable. Distracting images of the geometrical patterns formed by these perforations and ridges are reflected into the glass. A material such as a dark color, sprayed-on acoustical plaster seems desirable.

Several ceiling designs were investigated by the Consulting Illumination Engineer, L. F. Hornfeck, in his report. In addition to the conventional flat ceiling, four inclined ceiling designs were considered. These are shown in Figures 3-9 through 3-12, located at the end of this section.

The effect achieved by each ceiling design is limited by the Cosine Law, i.e., the intensity of the reflected light is diminished by the value of the cosine of the incident ray. Figure 3-8 presents a diagram

of a light ray impinging on each of several inclined ceilings. The values of the cosines for the angles of reflection are also indicated. It is apparent that the ceiling must be inclined at a large angle if a significant reduction in light intensity is to be achieved. The desire to reduce light intensity by the use of a sharply inclined ceiling must be tempered by the knowledge that the controller's vision should not be impaired. Also, the ceiling design should not drastically increase the volume of the tower cab; otherwise, the air conditioning load will be affected. This report did not consider the effect of the ceiling design on the acoustical characteristics of the cab. This factor should be studied prior to adoption of any radically new ceiling design.

As part of the overall ceiling design, consideration should be given to recessing those objects that now normally hang from the ceiling. Such objects include light guns and interior lights.

The reflectance value of black is zero. Ideally, then, the ceiling and interior of the cab should be painted black. However, it is known that the color black so extensively applied is psychologically oppressive and should be avoided. The colors used in the mock-up have low reflectance values; the highest is ten percent. Controller opinion data collected in the questionnaire indicated that the colors used were favorably received.

Bright ceilings, whether painted or internally illuminated, are to be avoided, because they do not absorb light.

Floor to Ceiling Height

The question was raised, "Does a local controller actually use the upper one foot of the tower cab window, and if so how often?" Several means of obtaining the information necessary to answer this question were considered. Finding a suitable approach proved to be very difficult, especially within the time limitation placed on the project.

One initially attractive proposal was to have the controller wear a head camera so as to photographically record his eye movements. This was rejected since it was not possible to fix the location of the controller in the cab or to immobilize the movements of his head. Unless these could be done, the analysis of the film could not be accomplished. Also, the use of an instrument affixed to the controller's head was rejected, because the position of the head does not necessarily indicate the position of the eyes.

After discussions with several of the seasoned tower controllers at NAFEC, it was decided information could best be obtained by human observation of the local controller position, especially if the observer were experienced with the job requirements and particular airport situation. Five air traffic control specialists with the required qualifications made trips to the field, one each to Philadelphia, Washington National, Norfolk, Idlewild and Pittsburgh. Additionally, observations of the local control position at Jacksonville were taken by a former member of the NAFEC controller pool. At each location the controller observer took four one-hour readings. The readings were taken when the arriving traffic was known to be greatest. The controller observer was to tally the number of times the local controller:

1. Looked up through the upper one foot of the glass, but did not lean over the console.

2. Looked up through the upper one foot of glass and did lean over the console.

3. Moved back from the console or stooped down and looked out the upper one foot of the glass at the rear or sides of the tower cab.

This information is presented in Table 3-5, located on the next page.

It is apparent from this limited sample that the controller does use the upper one foot of glass height to obtain information about aircraft under his control. A complete investigation of the number of times this portion of the glass is used, the attendant causes, and the effects achieved would comprise a lengthy operations research task. The data obtained would probably vary from tower to tower depending upon the aircraft population, the location of the approach paths, the landing aids available, etc. It is known that at certain congested airports traffic is required to report over the tower. At such locations the desire for additional upward visibility is apparent. The approach used by military jets and the climb characteristics of commercial air carrier jets also cause the controller to desire maximjm upward visibility. The data obtained at Jacksonville tower are indicative of this situation. Consideration might be given to increasing the floor to ceiling height or to redesigning and/or to rearranging the consoles so that the controller can be positioned closer to the glass.

Discussions with controllers indicate that VFR approaches are monitored more closely than IFR approaches and that approaches are

Table 3-5

OBSERVATION OF CONTROLLER VERTICAL VISION HABITS

Location and Tower Shape	Time of Day	Total Number of Approaches	Number of IFR Approaches	Number of Departures	Local Controller looks ahead and looks through upper 1 foot of glass	Local Controller leans over Console to obtain additional upward visibility	Local Controller moves back from or stoops down and looks through upper 1 ft. of glass at rear or sides of Tower Cab	ILS Runway in use
Philadelphia	10-1100	14	5	11	3	0	2	No
(Square Cab)	11-1200	14	10	6	8	9	4	No
	15-1600	17	9	10	7	5	3	No
	16-1700	14	3	8	7	3	8	No
TOTALS	4 Hours	59	27	35	25	17	17	
Pittsburgh	11-1200	21	17	7	4	3	0	No
(Square Cab)	12-1300	12	12	13	2	1	0	No
	15-1600	14	9	4	1	2	3	No
	16-1700	10	9	15	1	1	4	No
TOTALS	4 Hours	57	47	39	8	7	7	
Norfolk	1245-1345	15	0	9	2	0	5	No
(Square Cab)	14-1500	7	0	6	0	0	2	No
	1515-1615	11	2	9	2	0	4	No
	18-1900	8	0	5	3	0	4	No
TOTALS		41	2	29	7	0	15	

Table 3-5 Cont'd.

Location	Time	Number of Approaches	Number of IFR Approaches	Number of Departures	Local Controller Looks Up	Local Controller Leans Over Console	Local Controller Stoops Down	ILS Run-way in use
Washington	14-1500	38	25	28	14	3	7	No
D.C.	15-1600	30	24	26	11	2	6	No
(National)	17-1800	16	14	29	9	1	3	No
Irregular	18-1900	22	18	23	16	0	2	No
Octagon (T.								
S. O. Design)								
TOTALS	4 Hours	106	81	106	50	6	18	
Idlewild	1045-1145	19	0	29	5	1	1	No
Irregular	1245-1345	27	0	19	10	1	2	No
Octagon (T.	14-1500	27	0	16	12	1	6	No
S.O. Design)	16-1700	41	23	36	7	0	0	No
TOTALS		114	23	100	34	3	9	
Jacksonville	10-1100	29	0	25	23	6	6	No
	14-1500	22	0	13	7	3	4	No
Irregular	1530-1630	17	0	20	7	1	0	No
Octagon	1700-1800	40	0	12	9	0	5	No
TSO Design								
TOTALS	4 Hours	108	0	70	46	10	15	

monitored more closely than departures. The controller also increases the frequency with which he monitors an approaching aircraft as that aircraft commences the final approach. It is impossible, however, to ascribe a numerical value to the number of times a controller looks at approaching aircraft. The problem of floor to ceiling height also was studied by geometric analysis. The reduction in angles of upward visibility occasioned by a one-foot reduction in floor to ceiling height is shown in Figures 3-1 through 3-6. Corresponding values for the increase in range required to see an aircraft at a 1000 foot altitude are also presented.

By application of the previously mentioned formulas it was possible to compute the reduction in reflection area when the floor to ceiling height was decreased one foot. The values are shown in Table 3-6.

Table 3-6

REDUCTION IN REFLECTION AREA IN A PENTAGONAL CAB AS A FUNCTION OF CEILING HEIGHT

Ten Foot Ceiling Height	476 Square inches[1]
Nine Foot Ceiling Height	419 Square inches[1]

VERTICAL HEIGHT OF REFLECTION IN A PENTAGONAL CAB AS A FUNCTION OF CEILING HEIGHT

Glass Slope	12 1/2°	15°	17 1/2°	20°
Ten Foot Ceiling Height	22.7 in.[2]	19.2 in[2]	15.5 in.[2]	11.6 in.[2]
Nine Foot Ceiling Height	20.9 in.[2]	17.3 in.[2]	13.5 in.[2]	9.6 in.[2]

[1] For 15° Glass Slope.

[2] Measured above the sill of the glass.

From analysis of the photographs and from the location of the inflection points of the reflection areas computed from the mathematical formulas, it can be determined that when the ceiling is lowered the reflections are depressed, and the reflection area is reduced. The amount of reduction, however, is only a fraction of the ceiling height reduction.

Glass

Air traffic control tower cabs have been equipped with either single or double panes of polished plate glass, either tinted or non-tinted. The effects of these treatments are discussed below:

Single-pane, Untinted, Polished Plate Glass

The percentage of visible light that is transmitted through polished plate glass decreases very little with increases in glass thickness.

For example:

Thickness	Visible Light Transmitted
3/8 in.	86%
1/2 in.	85%
3/4 in.	82%

Untinted, polished plate glass transmits more infrared energy than does tinted glass. This infrared energy, we are told, cannot be removed satisfactorily by air conditioning. Its effects have been experienced by pilots in glass topped enclosures. The percentage of infrared energy that is transmitted decreases somewhat with an increase in glass thickness. For example:

Thickness	Transmitted Infrared Energy
3/8 in.	56%
1/2 in.	49%
3/4 in.	39%

Among the advantages of single-pane lights are:

1. An almost unlimited range of surface areas can be obtained; consequently, the number of metal window mullions required is reduced to a minimum.

2. The edges can be worked and joined to adjacent glass without a metal support, thereby eliminating supports at corners.

3. Reflections between the panes in a double glazed installation are avoided.

4. The colors of the controller's light gun (green and white) are more distinguishable when flashed through non-tinted glass, and single-pane installations normally are untinted.

The primary disadvantage of single-pane glass is its poor insulating property. When a sudden difference in exterior and interior temperatures occurs, the humidity in the air may condense on the inside of the glass.

Dual-Pane, Untinted, Polished Plate Glass

The principle advantage of double-glazed glass is the improvement in the insulating characteristics. Dust and condensation sometimes form between the panes of glass and impare visibility. A refinement of this type of installation occurs when the panes are contained in a metal and rubber framework, and the air is evacuated from between the panes of glass. The primary disadvantage is the limited surface area obtainable for use in tower cabs. The surface area is limited to 50 square feet, because the higher wind loads experienced at exposed elevations produce failures in the rubber seals encasing the glass. This surface area limitation would increase the number of metal window mullions in the proposed cab design from five to fifteen.

Tinted Glass

Tinting glass reduces the amount of visible light and infrared energy that passes through the glass. The reduction of each is considerable when compared with untinted, polished plate glass of equal thickness. Although it may be possible to obtain custom tinted glass with higher transmissivity, most tinted glass manufactured in the United States has the following characteristics:

Glass Thickness	Visible Light Transmitted	Infrared Energy Transmitted
3/8 in.	67%	11%
1/2 in.	60%	Approx. 8%
3/4 in.	49%	Approx. 8%

The tinted, double-glazed windows found in many tower cabs are composed of an outer pane of tinted glass and an inner pane of polished plate glass.

Present FAA regulations require that the glass used in tower cabs transmit 70-75% of the available light.

Non-Reflective Coatings for Glass

The use of non-reflective coatings for the glass is not considered to be feasible at this time. Discussions with representatives of the American Optical Company indicate that there are no facilities in the United States for coating a piece of glass larger than 9 square feet. It was felt that the industry would not undertake design of larger capacity machinery without some contractual arrangement.

The use of a non-reflective coating would improve visibility by that percent of the light that was no longer reflected by the glass surface but was now transmitted. Approximately 8% of the light impinging on a single thickness of glass is reflected; 4% from each surface. The harder, more durable non-reflective coatings that might withstand repeated window cleanings permit 50% of the rays that would normally be reflected to pass through the glass. A net improvement of possibly 4% in the light transmission might result.

"Invisible Glass"

A firm that custom designs invisible glass installations has been contacted and asked to view both the full sized tower cab and the scale models to determine if invisible glass could be utilized. No factual reply, other than verbal assurances of willingness to undertake funded study of the problem, has been received. "Invisible Glass" is curved and surface treated to control all reflections. It has been used extensively for store windows.

New Products

Corning Glass Company has recently started marketing a chemically hardened plate glass that can withstand significantly greater tensile stress than currently available glass. This could result in a reduction of the thickness of glass required. The product is known as "Chemcore."

Research is underway on means of producing a selective filtering glass. A light filtering solution would be contained between two panes of glass. Then, the filtering solution could be pumped between the glass panes when the brightness conditions required it. These products and others are either in the stages of research or final product development. Several manufacturers have indicated an interest in testing their products at NAFEC when they are available.

Interior Furnishings and Equipment

The outline form of type T-2 consoles was fabricated in masonite and installed on all sides of the full sized tower cab. Lighted instruments, switches, and other apparatus were not installed. The console mock-up was painted a non-reflecting, blue-black color (Martin Senour #N-M-S-2). No other furniture or equipment was installed.

Photographs of the working surfaces of several recently installed consoles were used to indicate the local and ground controller positions for the air traffic control specialists who were subjects for the questionnaire used in the operational approach to this investigation. Both simulated controller positions were located on one side of the cab, the side nearest the NAFEC ILS runway, 13-31. The simulated ground controllers position was established at the corner, and the local controller position was placed approximately four feet away.

Questionnaire responses indicated that the overall console design, overall ledge height, height and slope of the inclined face were regarded as satisfactory from both standing and sitting positions. Several comments were made that indicated that the width of the shelf (8 in.) should be increased.

For night illumination the tower cab was equipped with five recessed, incandescent light fixtures (Lightolier #7762). These were equally spaced on a ten-foot diameter circle whose center was the center of the cab. A dimmer control was placed in the lighting circuit.

Observations of the utility of this lighting arrangement were conducted. It was found that the glass reflected an image of the circle of light eminating from each fixture. This reflection of the pattern of the five ceiling lights was seen on all sides of the cab. The location of these ceiling lights was such that the illumination was behind the controller, causing him to write in his own shadow.

Night observations also were made of a back-lighted, glass writing surface arranged to the height and slope of the cab consoles. Reflections were minimized, since the emited light rays were largely absorbed or diffused by the ceiling. If future tests using a back-lighted, glass writing surface are conducted, incandescent lamps on a dimmer circuit should be used. The problem, here, seems to be to obtain enough light to see to write and yet not to destroy the controllers' night vision. The use of red light might also be investigated.

Since the tower cab was not equipped with instruments, the effect of lighted instruments was not observed. Principles found in Wright Air Development Center Report #54-160, "Visual Presentation of Information," Chapter Six, Instrument and Control Console Lighting, should provide some guidance in this area.

TABLE FOR ANGLES OF
ELEVATION AND DEPRESSION
AT OTHER AZIMUTH POSITIONS

AZIMUTH	ANGLE OF DEPRESSION	ANGLE OF ELEVATION		MINIMUM RANGE OF VISIBILITY AT 1000 FT. ALTITUDE *	
		9'0" CEILING	10'0" CEILING	9'0" CEILING	10'0" CEILING
0°	21.0°	24.5°	29.3°	2194 FT.	1782 FT.
20°R	24.9°	28.0°	35.5°	1881 FT.	1402 FT.
40°R	25.7°	29.0°	34.2°	1804 FT.	1472 FT.
60°R	24.0°	27.0°	31.8°	1963 FT.	1613 FT.
80°R	19.1°	22.0°	26.5°	2475 FT.	2006 FT.
100°R	12.0°	13.5°	16.8°	4165 FT.	3312 FT.
120°R	8.5°	13.0°	16.5°	4331 FT.	3376 FT.
140°R	7.5°	11.4°	14.2°	4959 FT.	3952 FT,
160°R	5.9°	9.5°	12.0°	5976 FT.	4705 FT.
180°R	6.3°	10.0°	12.5°	5671 FT.	4511 FT.

FIG. 3 - 1 PENTAGONAL TOWER CAB - SIDES AND GLASS AT $12\frac{1}{2}$° ANGLE OF INCLINATION (400 SQUARE FEET OF FLOOR AREA)

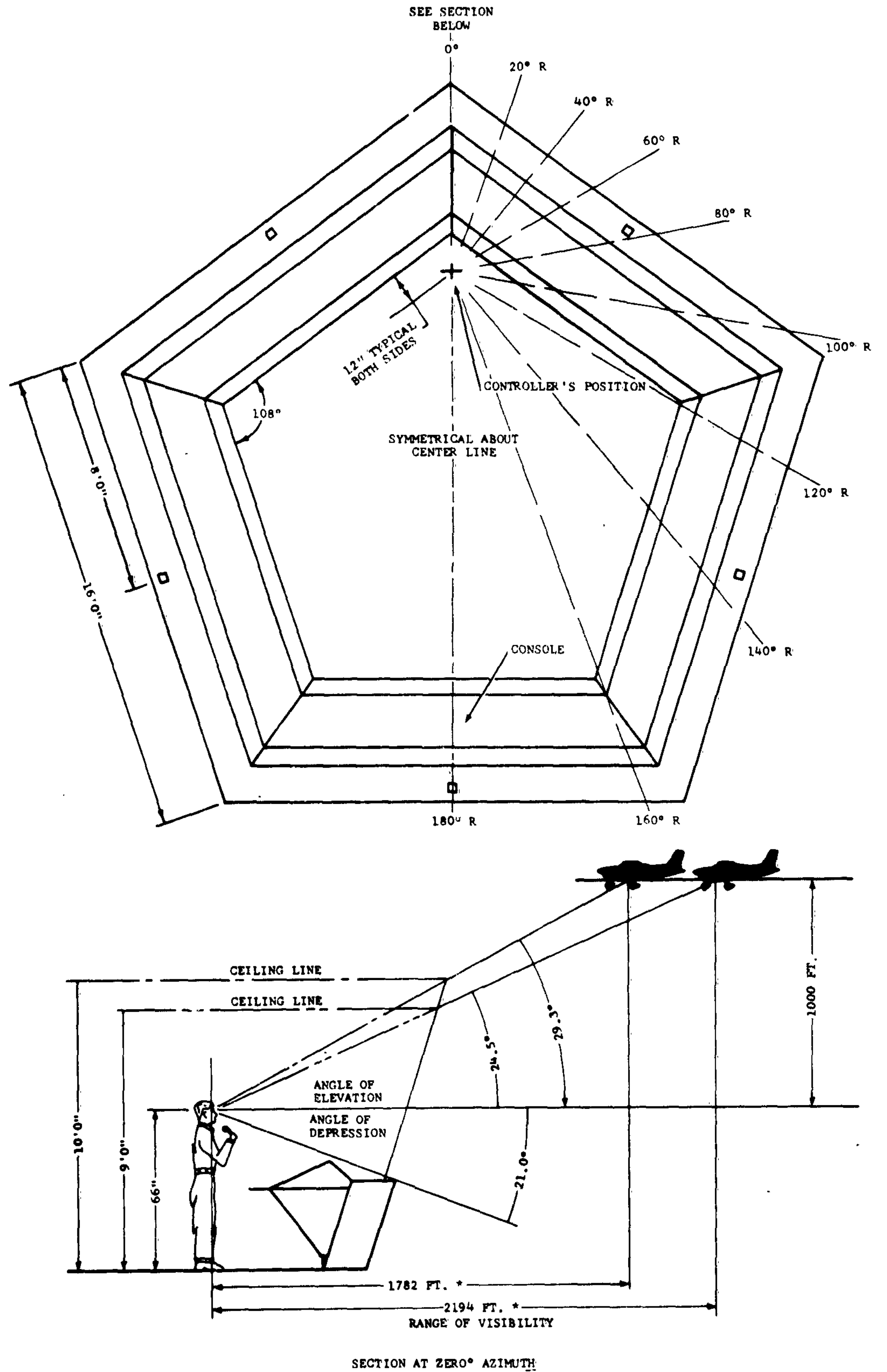


FIG. 3 - 1 PENTAGONAL TOWER CAB - SIDES AND GLASS AT 12 1/2° ANGLE OF INCLINATION (400 SQUARE FEET OF FLOOR AREA)

TABLE FOR ANGLES OF
ELEVATION AND DEPRESSION
AT OTHER AZIMUTH POSITIONS

AZIMUTH	ANGLE OF DEPRESSION	ANGLE OF ELEVATION 9'0" CEILING	ANGLE OF ELEVATION 10'0" CEILING	MINIMUM RANGE OF VISIBILITY AT 1000 FT. ALTITUDE * 9'0" CEILING	MINIMUM RANGE OF VISIBILITY AT 1000 FT. ALTITUDE * 10'0" CEILING
0°	21.0°	23.5°	28.0°	2300 FT.	1881 FT.
20°R	24.9°	27.2°	31.8°	1946 FT.	1613 FT.
40°R	25.7°	28.0°	32.9°	1881 FT.	1546 FT.
60°R	24.0°	25.7°	30.5°	2078 FT.	1698 FT.
80°R	19.1°	21.0°	25.0°	2605 FT.	2144 FT.
100°R	12.0°	13.0°	16.3°	4332 FT,	3420 FT.
120°R	8.5°	12.9°	16.0°	4366 FT.	3487 FT.
140°R	7.5°	11.0°	14.0°	5144 FT.	4011 FT.
160°R	5.9°	9.5°	12.0°	5976 FT.	4705 FT.
180°R	6.3°	10.0°	12.5°	5671 FT.	4511 FT.

FIG. 3 - 2 **PENTAGONAL TOWER CAB - SIDES AND GLASS AT 15° ANGLE OF INCLINATION (400 SQUARE FEET OF FLOOR AREA)**

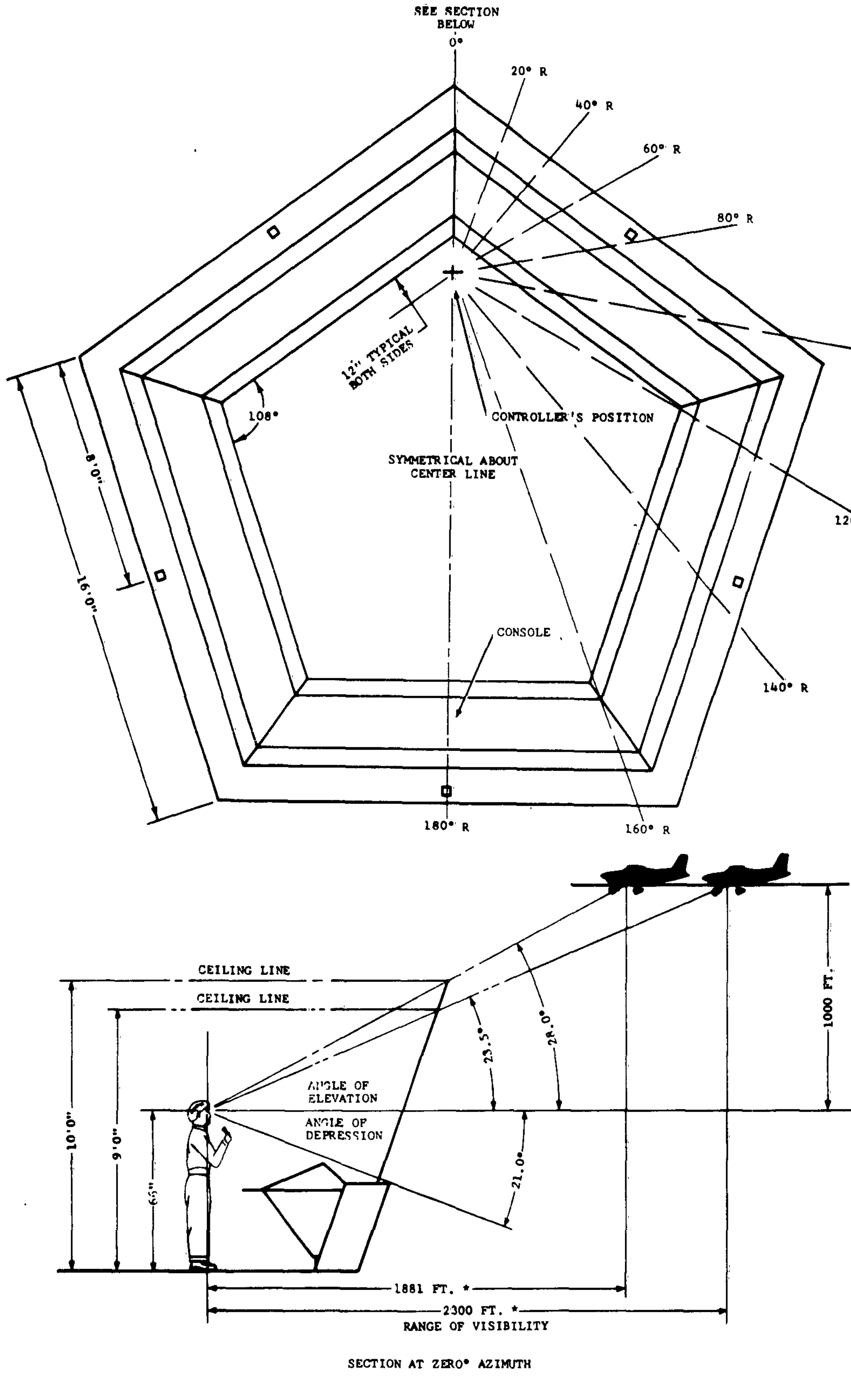


FIG. 3 - 2 PENTAGONAL TOWER CAB - SIDES AND GLASS AT 15° ANGLE OF INCLINATION (400 SQUARE FEET OF FLOOR AREA)

TABLE FOR ANGLES OF
ELEVATION AND DEPRESSION
AT OTHER AZIMUTH POSITIONS

AZIMUTH	ANGLE OF DEPRESSION	ANGLE OF ELEVATION		MINIMUM RANGE OF VISIBILITY AT 1000 FT. ALTITUDE *	
		9'0" CEILING	10'0" CEILING	9'0" CEILING	10'0" CEILING
0°	21.0°	22.6°	27.0°	2402 FT.	1963 FT.
20°R	24.9°	26.4°	31.0°	2014 FT.	1664 FT.
40°R	25.7°	27.0°	31.8°	1963 FT.	1613 FT.
60°R	24.0°	24.7°	29.5°	2174 FT.	1768 FT.
80°R	19.1°	20.2°	24.5°	2718 FT.	2194 FT.
100°R	12.0°	12.8°	16.1°	4402 FT.	3465 FT.
120°R	8.5°	12.5°	15.8°	4511 FT.	3534 FT.
140°R	7.5°	10.8°	13.8°	5242 FT.	4071 FT.
160°R	5.9°	9.5°	11.6°	5976 FT.	4872 FT.
180°R	6.3°	10.0°	12.5°	5671 FT.	4511 FT.

FIG. 3 - 3 PENTAGONAL TOWER CAB - SIDES AND GLASS AT $17\frac{1}{2}°$ ANGLE OF INCLINATION (400 SQUARE FEET OF FLOOR AREA)

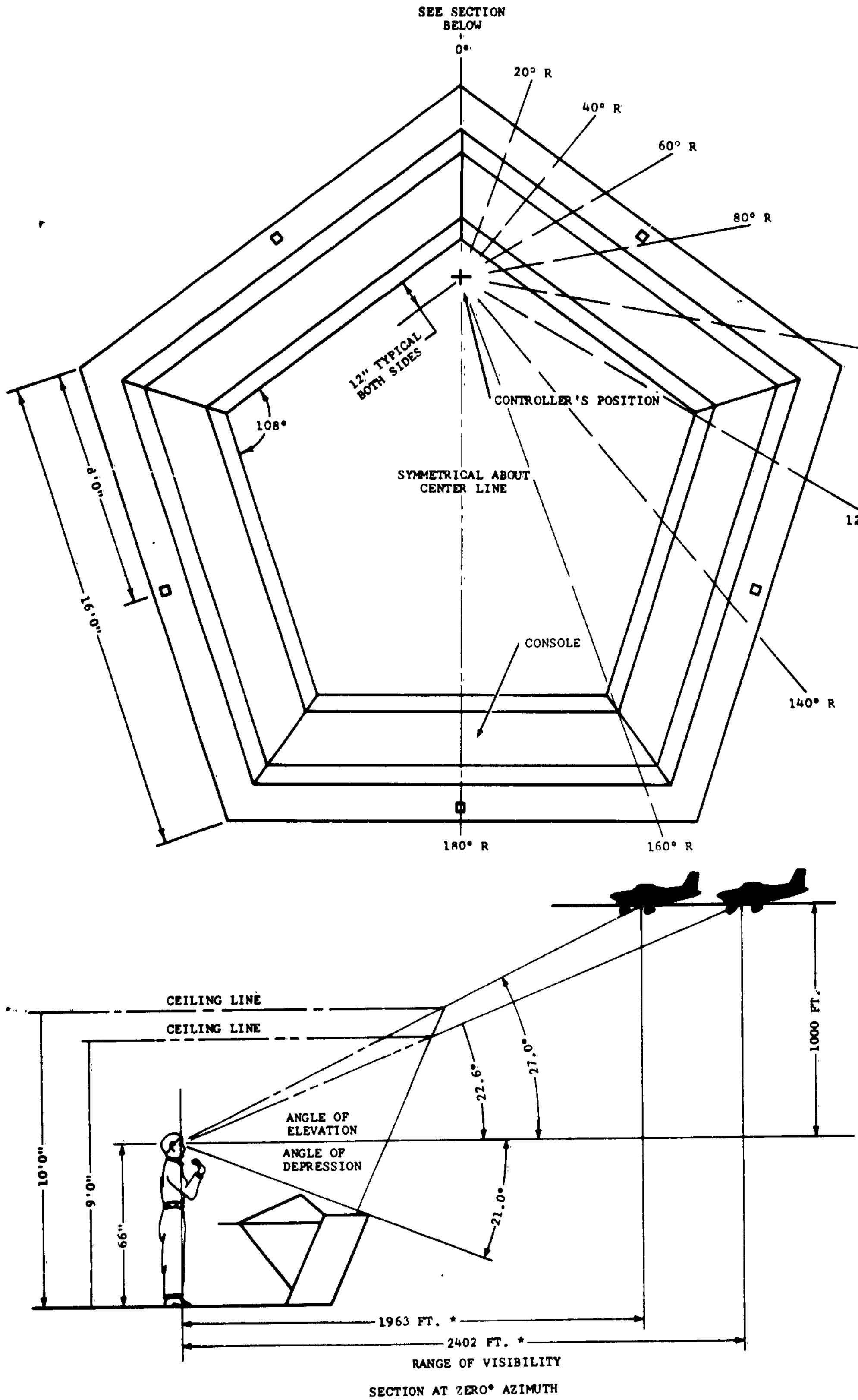


FIG. 3 - 3 PENTAGONAL TOWER CAB - SIDES AND GLASS AT 17 1/2° ANGLE OF INCLINATION (400 SQUARE FEET OF FLOOR AREA)

TABLE FOR ANGLES OF
ELEVATION AND DEPRESSION
AT OTHER AZIMUTH POSITIONS

AZIMUTH	ANGLE OF DEPRESSION	ANGLE OF ELEVATION		MINIMUM RANGE OF VISIBILITY AT 1000 FT. ALTITUDE *	
		9'0" CEILING	10'0" CEILING	9'0" CEILING	10'0" CEILING
0°	25.5°	28.0°	33.1°	1881 FT.	1534 FT.
20°R	24.3°	25.8°	30.8°	2069 FT.	1678 FT.
40°R	23.1°	25.3°	30.5°	2116 FT.	1698 FT.
60°R	22.2°	24.6°	29.7°	2184 FT.	1753 FT.
80°R	19.3°	22.0°	26.1°	2475 FT.	2041 FT.
100°R	13.5°	15.7°	19.4°	3558 FT.	2840 FT.
120°R	9.5°	13.7°	17.0°	4102 FT.	3271 FT.
140°R	8.2°	12.6°	16.0°	4474 FT.	3487 FT.
160°R	7.7°	11.8°	14.6°	4787 FT.	3839 FT.
180°R	7.0°	10.8°	13.6°	5242 FT.	4134 FT.

FIG. 3 - 4 MODIFIED OCTOGONAL TOWER CAB - GLASS AT 15° ANGLE OF INCLINATION (400 SQUARE FEET OF FLOOR AREA)

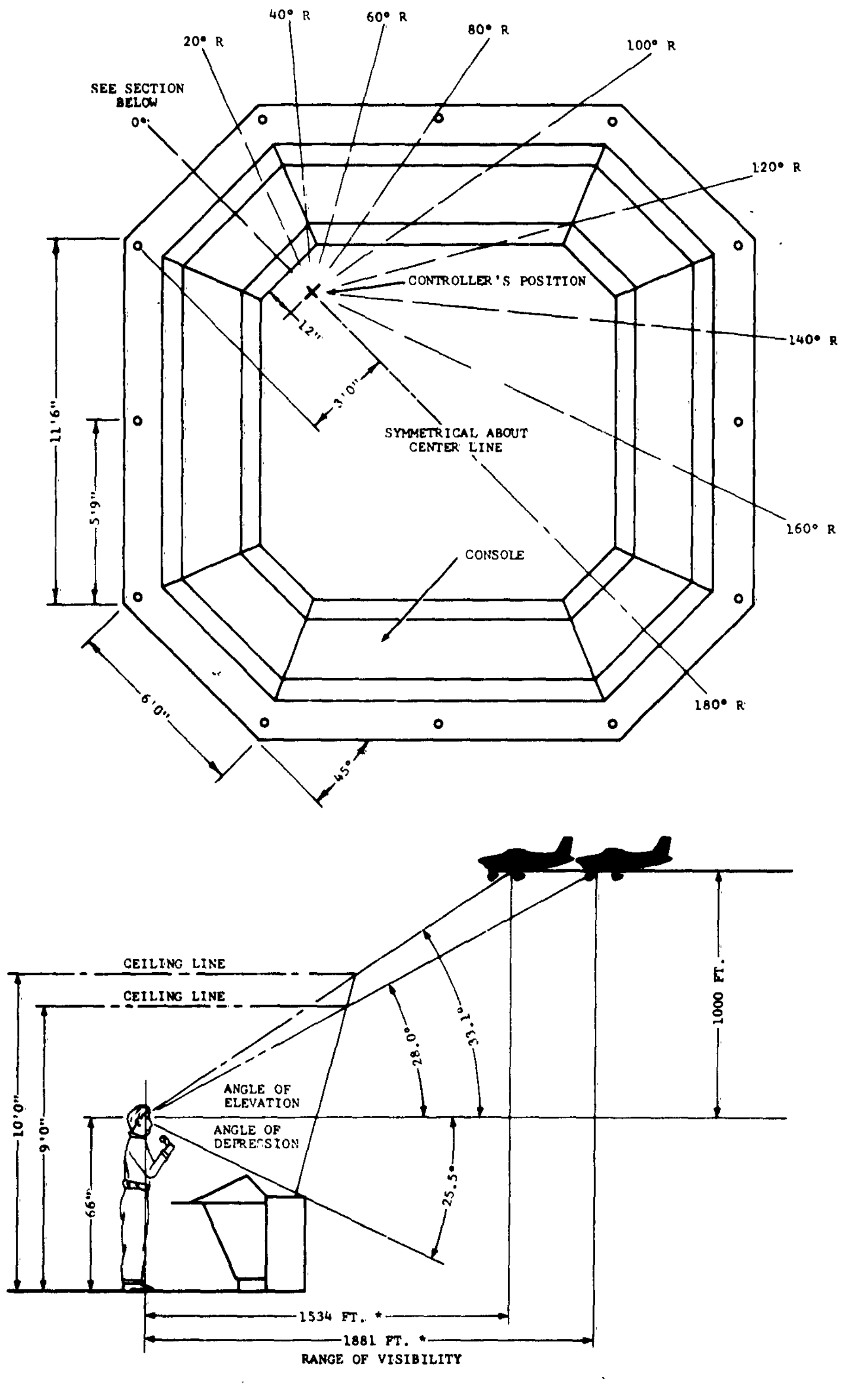


FIG. 3 - 4 MODIFIED OCTAGONAL TOWER CAB - GLASS AT 15° ANGLE OF INCLINATION (400 SQUARE FEET OF FLOOR AREA)

TABLE FOR ANGLES OF
ELEVATION AND DEPRESSION
AT OTHER AZIMUTH POSITIONS

AZIMUTH	ANGLE OF DEPRESSION	ANGLE OF ELEVATION 9'0" CEILING	ANGLE OF ELEVATION 10'0" CEILING	MINIMUM RANGE OF VISIBILITY AT 1000 FT. ALTITUDE * 9'0" CEILING	MINIMUM RANGE OF VISIBILITY AT 1000 FT. ALTITUDE * 10'0" CEILING
0°	18.0°	20.5°	24.6°	2675 FT.	2184 FT.
20°R	22.6°	25.5°	30.1°	2096 FT.	1725 FT.
40°R	24.8°	28.2°	32.7°	1865 FT.	1558 FT.
60°R	24.2°	26.0°	32.0°	2050 FT.	1600 FT.
80°R	20.7°	23.5°	28.0°	2300 FT.	1881 FT.
100°R	14.6°	16.6°	20.0°	3354 FT.	2748 FT.
120°R	7.9°	12.3°	15.0°	4586 FT.	3732 FT.
140°R	8.0°	12.5°	15.5°	4511 FT.	3606 FT.
160°R	7.4°	11.5°	14.3°	4915 FT.	3923 FT.
180°R	5.6°	9.0°	11.3°	6314 FT.	5004 FT.

FIG. 3 - 5 SQUARE TOWER CAB - GLASS AT 15° ANGLE OF INCLINATION
(400 SQUARE FEET OF FLOOR AREA)

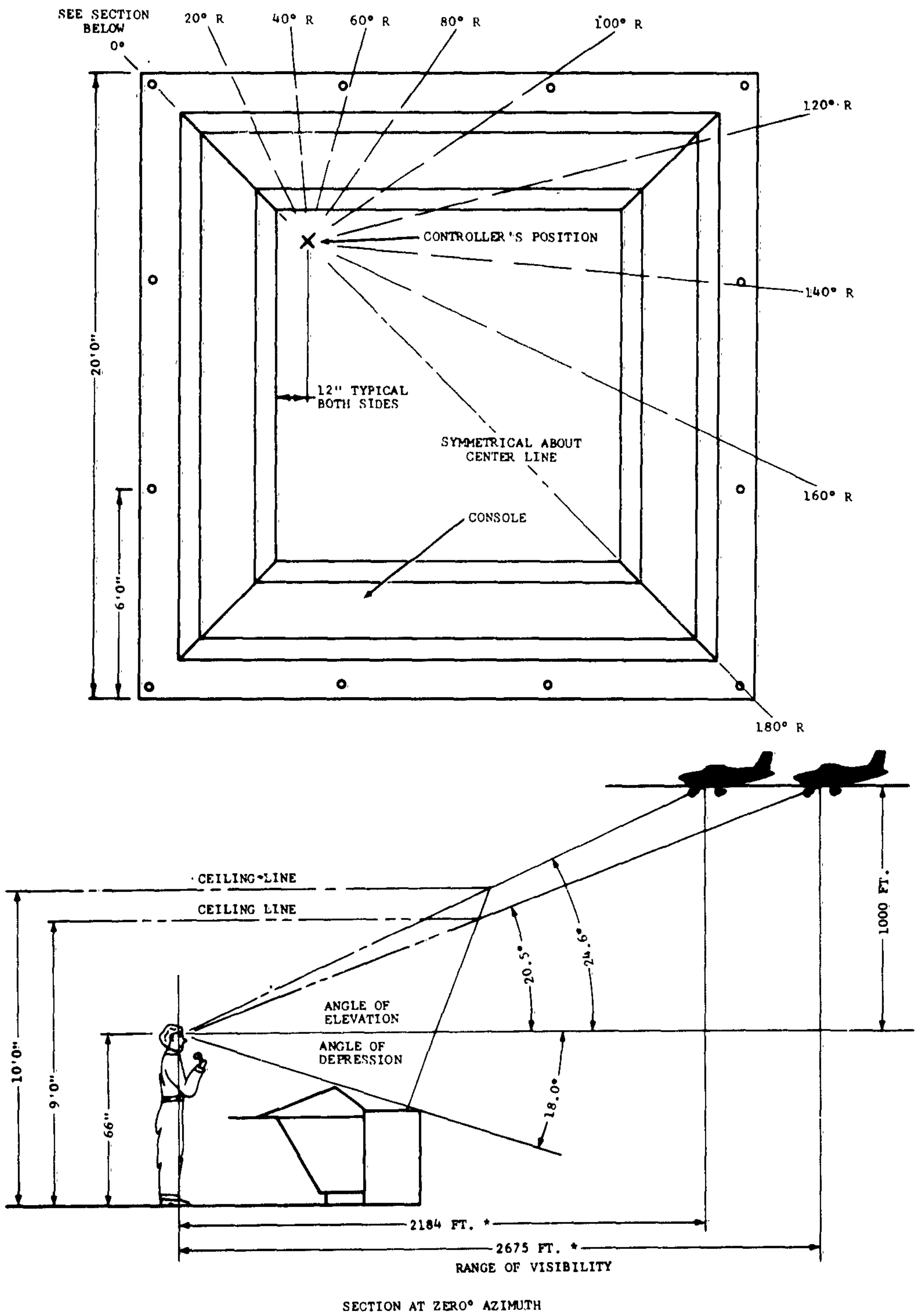
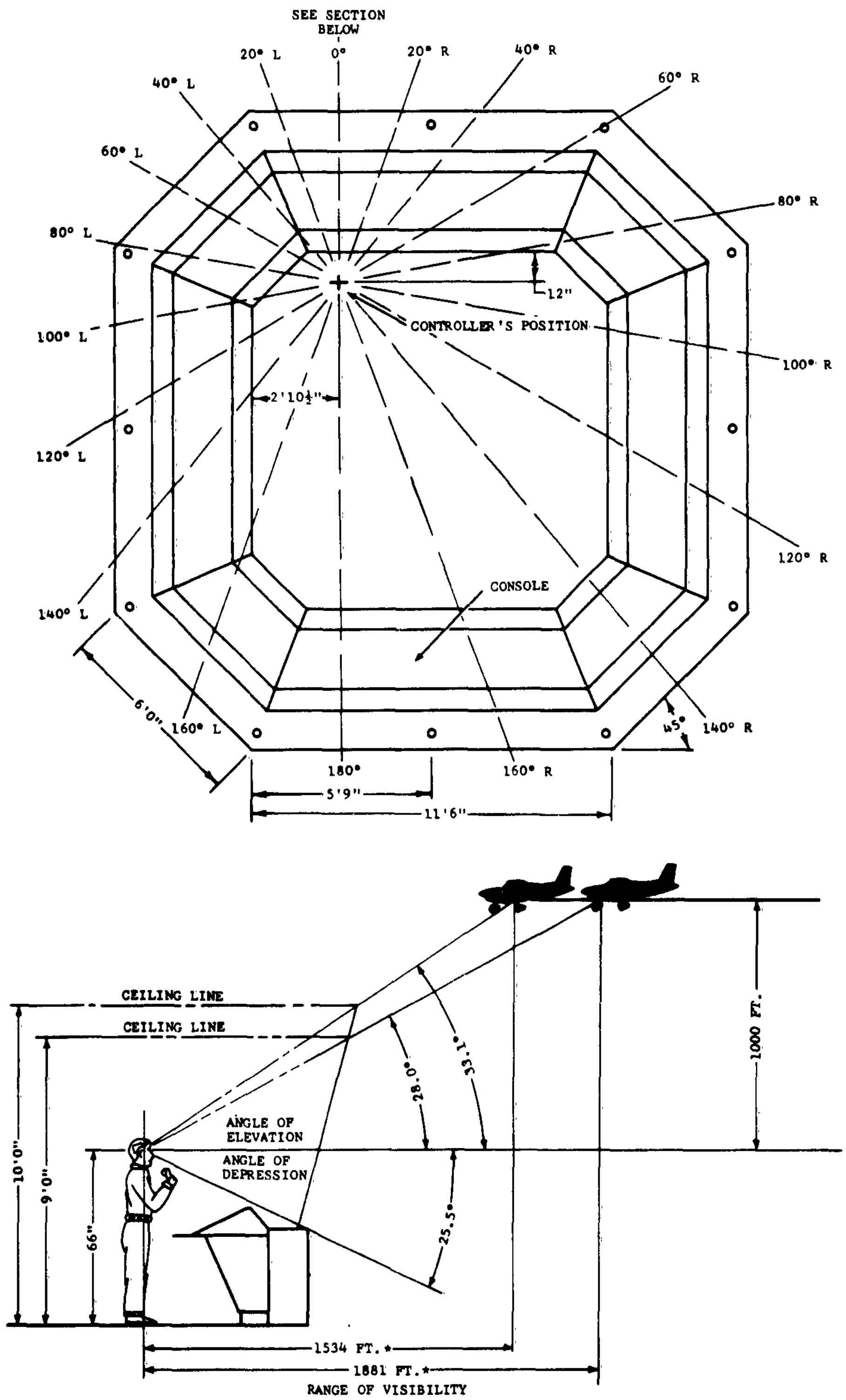


FIG. 3 - 5 SQUARE TOWER CAB - GLASS AT 15° ANGLE OF INCLINATION (400 SQUARE FEET OF FLOOR AREA)

TABLE FOR ANGLES OF
ELEVATION AND DEPRESSION
AT OTHER AZIMUTH POSITIONS

AZIMUTH	ANGLE OF DEPRESSION	ANGLE OF ELEVATION 9'0" CEILING	ANGLE OF ELEVATION 10'0" CEILING	MINIMUM RANGE OF VISIBILITY AT 1000 FT. ALTITUDE * 9'0" CEILING	MINIMUM RANGE OF VISIBILITY AT 1000 FT. ALTITUDE * 10'0" CEILING
0°	25.5°	28.0°	33.1°	1881 FT.	1534 FT.
20°L	24.0°	26.3°	31.0°	2023 FT.	1664 FT.
20°R	24.0°	26.3°	31.0°	2023 FT.	1664 FT.
40°L	23.4°	25.8°	30.8°	2069 FT.	1678 FT.
40°R	19.6°	21.7°	26.0°	2513 FT.	2050 FT.
60°L	22.5°	25.3°	30.2°	2116 FT.	1718 FT.
60°R	14.0°	16.5°	20.5°	3376 FT.	2675 FT.
80°L	19.5°	22.1°	26.7°	2463 FT.	1988 FT.
80°R	10.4°	14.3°	17.6°	3923 FT.	3152 FT.
100°L	18.3°	22.0°	26.6°	2475 FT.	1997 FT.
100°R	9.1°	13.8°	17.0°	4071 FT.	3271 FT.
120°L	16.0°	20.0°	24.2°	2747 FT.	2225 FT.
120°R	8.1°	12.1°	15.0°	4665 FT.	3732 FT.
140°L	12.2°	15.0°	18.2°	3732 FT.	3042 FT.
140°R	7.0°	11.1°	14.0°	5097 FT.	4011 FT.
160°L	8.9°	13.0°	16.0°	4331 FT.	3487 FT.
160°R	7.5°	11.5°	14.5°	4915 FT.	3867 FT.
180°	8.2°	12.4°	15.4°	4548 FT.	3630 FT.

FIG. 3 - 6 MODIFIED OCTOGONAL TOWER CAB - GLASS AT 15° ANGLE OF INCLINATION (400 SQUARE FEET OF FLOOR AREA)



SECTION AT ZERO° AZIMUTH

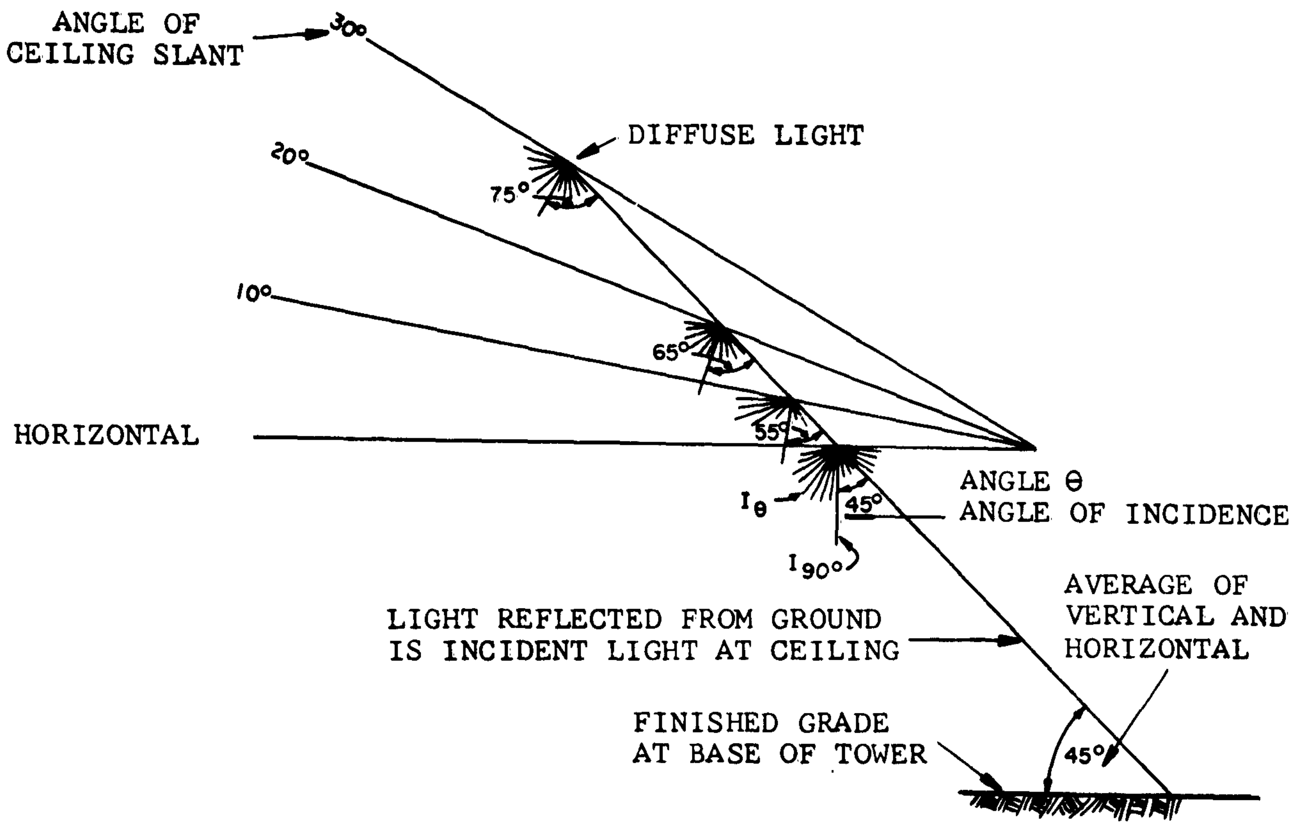
FIG. 3 - 6 MODIFIED OCTAGONAL TOWER CAB - GLASS AT 15° ANGLE OF INCLINATION (400 SQUARE FEET OF FLOOR AREA)

FIGURE 3-7

PENTAGONAL TOWER CAB - SIDES AND GLASS AT 20 DEGREE ANGLE OF INCLINATION (400 SQUARE FOOT FLOOR AREA)

Azimuth	Upward Elevation as limited by the ten foot floor to ceiling height	Minimum Range of Visibility to an Aircraft at 1000 foot altitude
0°	26°	2050 ft.
20°	30°	1743 ft.
40°	31.5°	1635 ft.
60°	27.5°	1920 ft.
80°	23.0°	2360 ft.
100°	14°	4560 ft.
120°	15°	3730 ft.
140°	12.2°	4650 ft.
160°	11.5°	4910 ft.
180°	12.2°	4650 ft.

Refer to Figure 3-3 for diagrams.

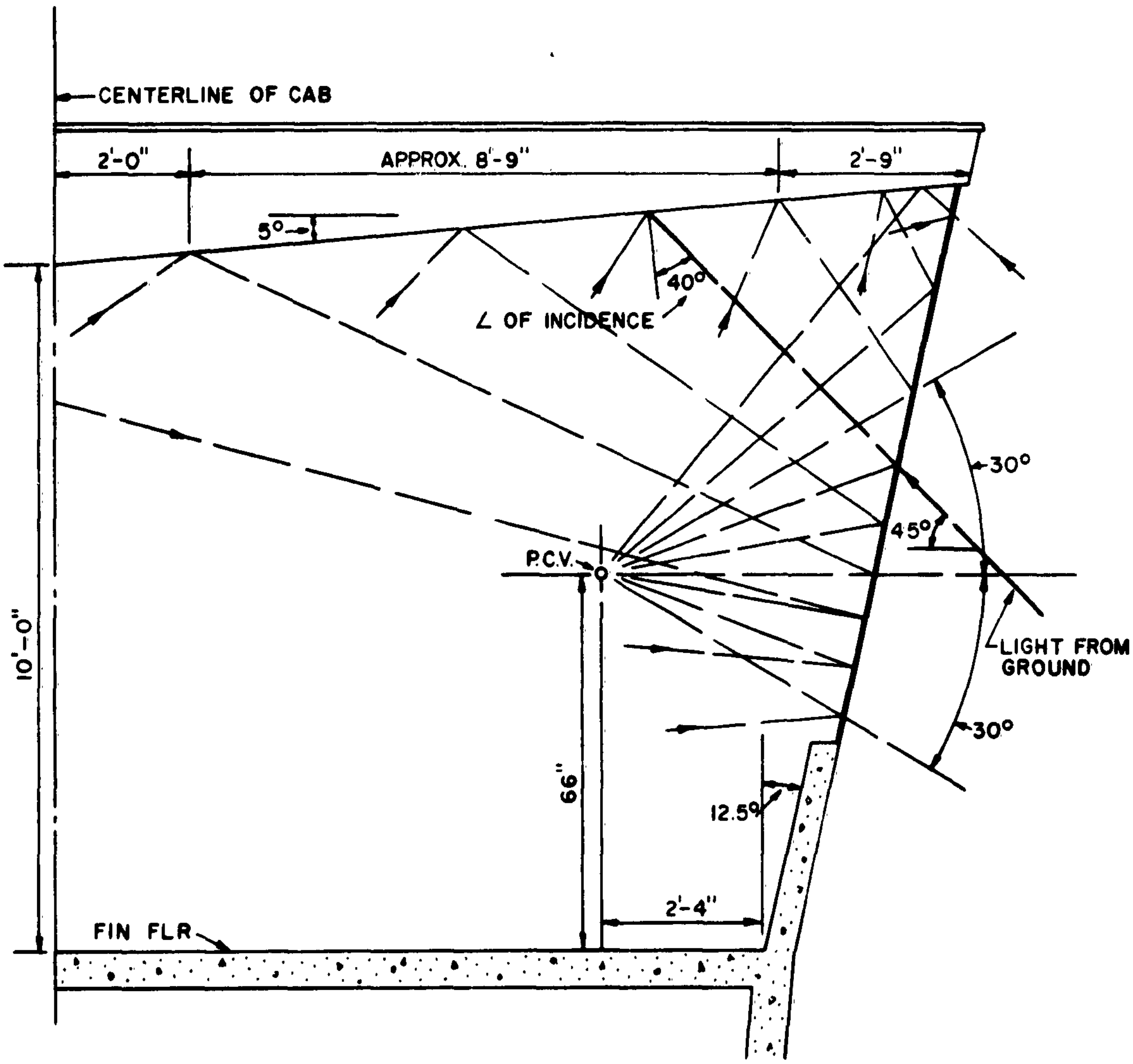


COSINES OF ANGLES

0°	1.0	45°	.707
5°	.996	50°	.643
10°	.985	55°	.574
15°	.966	60°	.5
20°	.940	65°	.423
25°	.906	70°	.342
30°	.866	75°	.259
35°	.819	80°	.174
40°	.766	85°	.087

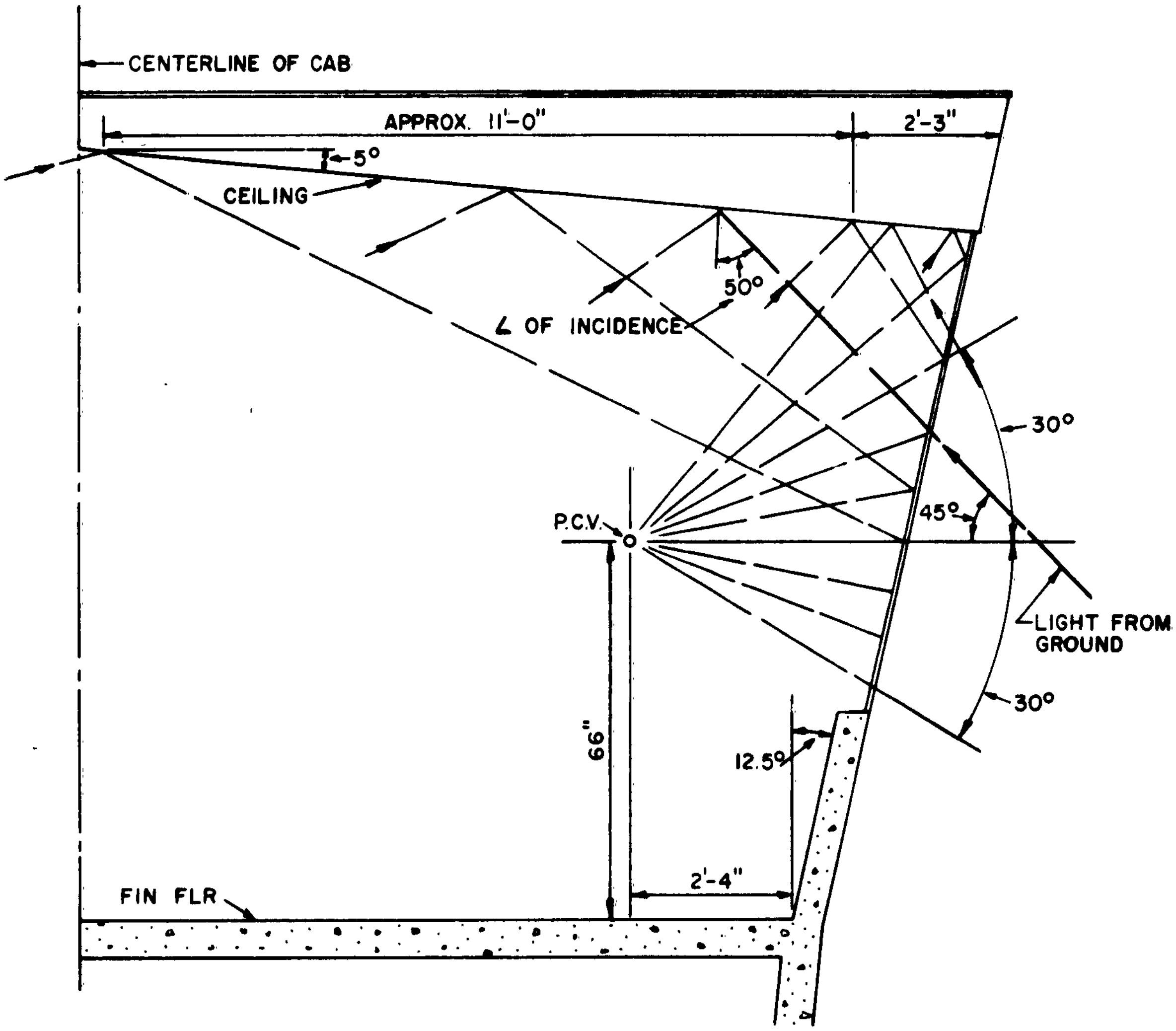
$I_\theta = I_{90°}$ COSINE θ

FIGURE 3-8



LIGHT RAY PLOT SHOWING CEILING
SLOPED UP TO WINDOW
SCALE: 3/8" = 1'-0"
$I_\theta = I_{90^\circ}$ COSINE 40°

FIGURE 3-9

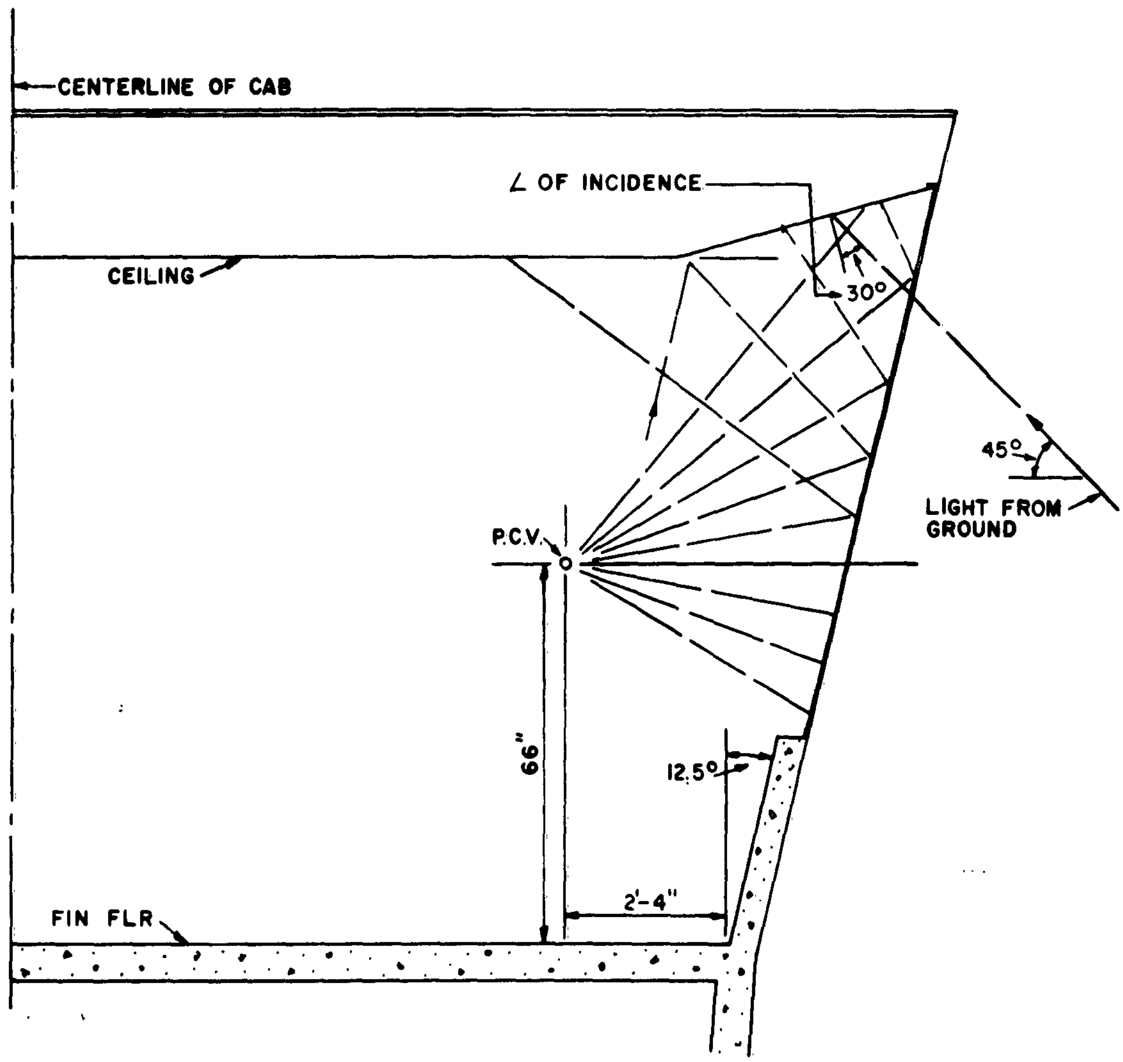


LIGHT RAY PLOT SHOWING CEILING
SLOPED UP TO CENTER OF CAB

SCALE: 3/8" = 1'-0"

$I_{\theta} = I_{90^{\circ}}$ COSINE 50°

FIGURE 3-10

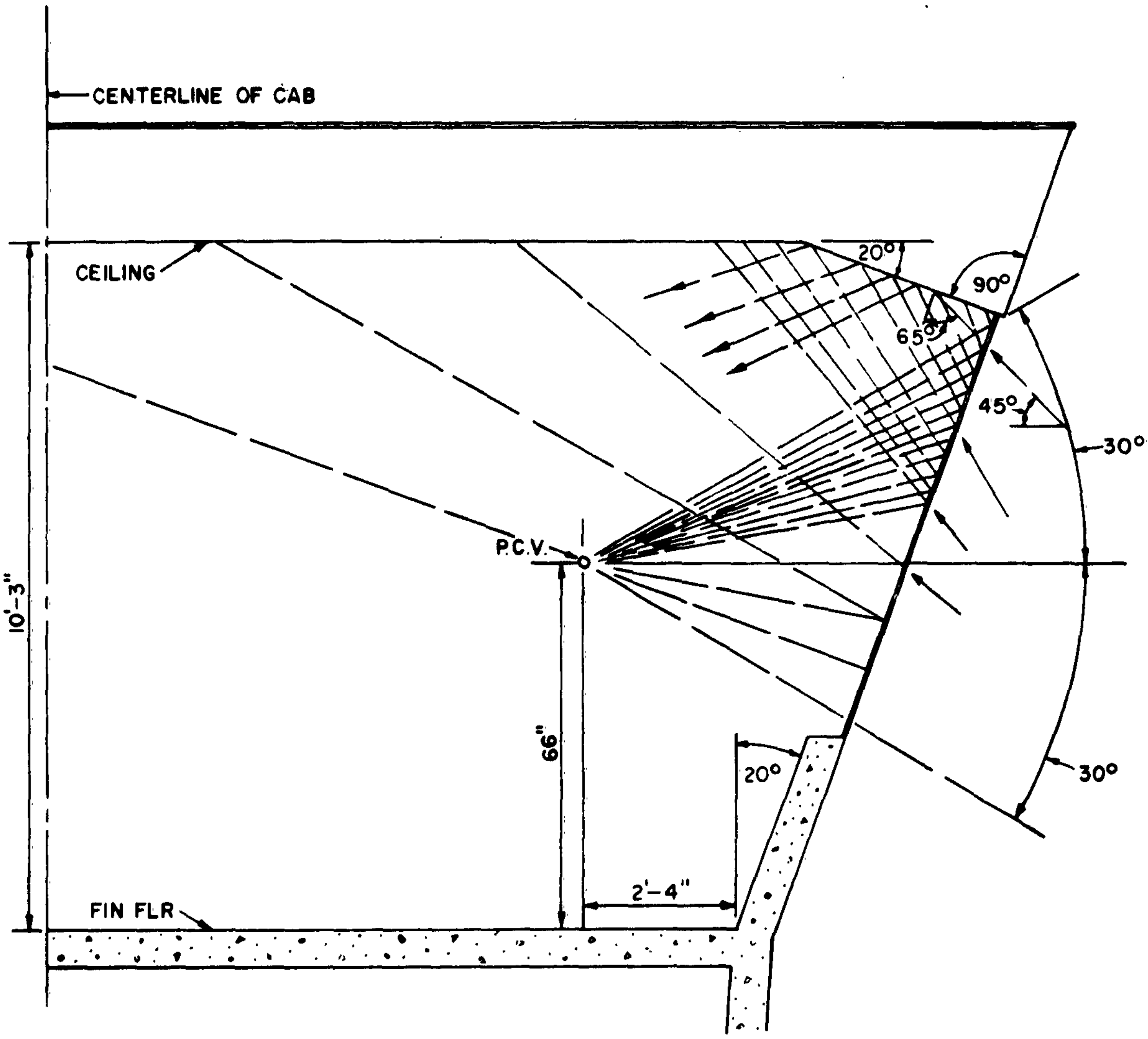


LIGHT PLOT SHOWING CEILING
SLOPED UP TO WINDOW

SCALE: 3/8" = 1'-0"

$I_{\theta} = I_{90°}$ COSINE 30°

FIGURE 3-11



LIGHT RAY PLOT SHOWING CEILING
SLOPED DOWN AT CAB WINDOW
SCALE: 3/8" = 1'-0"
$I_\theta = I_{90^\circ}$ COSINE 65°

FIGURE 3-12

Controller Reaction to Job Environment Factors

In order to evaluate systematically the opinions of air traffic controllers, with regard to the proposed pentagonal tower, a sample of 49 controllers was selected from the controller test pool of the Technical Services Division, ATC Laboratories Facilities Branch. All these men have had recent experience in air traffic control and have worked at various airports in the United States. Each man attended one of eight test sessions and filled out a questionnaire. The sessions were held at various times of the day and night to insure that the cab would be observed under a wide variety of conditions. Over a two day period, eight groups of six or seven men each were brought to the tower for two-hour periods at either sunrise, midafternoon, sunset, or night and asked to familiarize themselves with the tower cab features before answering the questionnaire. Upon arriving in the cab they were assigned randomly to positions of local or ground control and asked to evaluate the cab with reference to the assigned job. The subjects were asked not to talk among themselves during the observation period. A copy of the full questionnaire is given as Appendix D to this report.

The statistical analysis and write up of this work was performed by Mr. Lee Paul, a psychologist in the Research Division.

Rating of Job Relevant Features

To determine which cab design elements were considered most job relevant, the subjects were asked to rate 26 features on a three point scale:

No impact on the job.

Moderate impact on the job.

Strong impact on the job.

The purpose of this part of the questionnaire was to guide tower designers toward giving their attention to design elements which affect control operations.

Since a single control cab design must accommodate both local and ground controllers, the data from the two arbitrarily assigned groups was combined. Perusal of the data indicated that, on this part of the questionnaire, both groups were in close accord on the relative

importance of the various features. In order to perform a statistical analysis of the responses, weights were assigned to the alternatives as follows:

No impact on job -- 0
Moderate impact on job -- 1
Strong impact on job -- 2

The mean rating of each feature was computed and is shown in Table 3-7 at the end of this section. The five highest rated items concerned not specific design features, but "ability to see" various parts of the airport and the aircraft as follows: both ends of the active runway, runway turn-offs, aircraft on final approach, taxiways, and run-up areas. These items are not specific design features, but rather functions of the controller that a good design would enhance. They should, thus, be considered as important criteria against which a specific tower cab configuration might be measured.

The next most important features concerned the cab itself: overall console design, relationship among different controller's positions, reflections on glass in locations other than corners, large uninterrupted glass areas and the number of visual obstructions. Three of these items relate directly to the aforementioned problem of visual surveillance and, thus, confirm the almost universally held concept that the primary function of the control cab is to facilitate visual monitoring of aircraft movements both on the airport surface and in the air near the airport.

The remaining items were assigned lesser degrees of importance, but the last three were rated extremely low, i.e., 49% of the respondents considered the number of cab sides of no importance, 60% rated the catwalk railing in the lowest category, and 78% felt the presence or absence of a catwalk made no difference. With regard to the number of sides a cab should have, the controllers said this was a design feature which was unimportant to their job performance. As for the catwalk and its railing, it appears that the controllers were seldom, if ever, required to clean the outside of the window, so that the equipment required for this task had little interest for them.

Rating of Design Features

Next, the controllers were asked to compare various features (see Table 3-8 located at the end of this section) of the pentagonal cab they

were in with that of another tower with which they were familiar. Twenty-five of the controllers chose to make the comparison with a regular octagonal cab (a geometric shape similar to the operational NAFEC tower), 17 compared it with a square cab (a shape similar to the Pittsburgh Tower), and 2 compared it with an irregular octagonal cab (like Idlewild Tower). Because of the limited sample (2 cases), the last set of comparisons has been omitted from this analysis. Although specific towers were not designated for the comparisons, certain patterns in the responses on the regular octagonal tower suggest that most of the controllers actually were comparing it with the NAFEC Tower. The almost unanimous preference for the pentagonal tower's "large uninterrupted areas of glass," "amount of floor space," and "height of tower cab above the ground" seems to indicate that the controllers were using the same tower as a comparison. This amount of agreement never occurred in the comparisons with the square cab where the probability is extremely low that the controllers were using a common referent. Note that the NAFEC Tower differs in multiple respects from the proposed tower mock-up, notably in height above the ground and amount of floor space.

In order to quantify and analyze the results, weights were assigned to the alternatives such that a high score indicated a preference for the pentagonal tower, while a low score favored the 4 or 8 sided tower.

Table 3-8 shows the mean ratings for both the four and eight sided cab comparisons for each of the 26 features. A null hypothesis that there was no difference between the pentagonal cab and the cab with which it was being compared was tested by the use of Student's "t" test.

The results are shown in Table 3-8, located at the end of this section.

The value "P" indicates the probability that a difference as large as the one that occurred could be expected to occur by chance. Values less than 1 in 10, or .10 are not shown as they are too near chance exception to warrant interpretation. The following features of the pentagonal cab were preferred at least to the .05 level of confidence (preferences this large would not be expected to occur by chance more often than 1 time in 20):

Large Uninterrupted Areas of Glass

Amount of Floorspace

Number of Sides

Interior Paint Dark

Overall Console Design

Height Above Ground

Ability to See Both Ends of Runway

Ability to See Runway Turnoffs

Ability to See Taxiways

Ability to See Run-Up Areas

Ability to See Ramp Areas

Ability to See Aircraft on Final Approach

Reflections on Glass Only in the Corners

Location of Visual Obstructions

Number of Visual Obstructions

Seven of the above items seem to relate more to height and location of the tower than to specific differences in cab design, while 8 features were definitely associated with cab design. In all the cases there was a statistically significant preference in favor of the pentagonal cab. While these findings are of unquestioned interest, caution should be used in arriving at any firm conclusions since there is a strong possibility that the data may be influenced by "halo effect." This is a tendency to rate all the features of the generally preferred item higher than if each were independently considered. For example, if the additional height of the pentagonal cab was considered very desirable, the advantage might well carry over to other aspects of the tower. An example of this is in item #23, "Reflections on glass only in the corners." While the controllers indicated a preference for the pentagonal cab on this feature, data from photographs and models indicate that corner reflections are smaller and less conspicuous in the irregular octagonal cab. It

seems quite reasonable that ratings of this feature are confounded with other differences in the two cabs.

When compared to a square cab the pattern of preferences was not as clear cut. The already mentioned possibility that many different towers were used as referents may provide part of the explanation. Also, since the sample size is smaller, differences of the same magnitude are less apt to reach the same level of statistical significance. Of course the most obvious explanation is that there is less difference between square and pentagonal cabs than between pentagonal and irregular octagonal cabs. The following features of the pentagonal cab were significantly preferred at the .05 level of confidence; at least:

Large Uninterrupted Areas of Glass

Tilt or Outward Slope of Glass

All Interior Paint Dark

Height of Writing Surface

Height of Cab Above Ground

Ability to See Taxiways

Ability to See Runup Areas

Location of Visual Obstructions

Number of Visual Obstructions

Again, the pentagonal cab was preferred to the square cab for all those features considered.

Assessment of Diagrams

The controllers were also asked to state their operational preferences with respect to four generalized features of tower design and location. These features were:

1. A five sided (non-parallel sides) versus a six sided (parallel sides) cab configuration.

2. The controller is positioned at the intersection of two sides as opposed to having him positioned at the middle of a side.

3. Having a corner of the tower facing an active runway versus having the near side parallel to the active runway.

4. Having the tower located on the apron versus having it located across the active runway from the apron.

Sixteen diagrams were made up representing all combinations of the above variables, and each diagram was rated on a five point scale from "very poor" to "very good" (See diagrams in Appendix). Since different positions were specified for local and ground controllers, a separate analysis was made.

The method of analyzing these data consisted in pairing the ratings made by each controller. That is, there were 8 pairs of diagrams that differed only in whether a pentagonal or hexagonal cab was used. The same 16 diagrams could also be divided into 8 pairs that differed in cab orientation, while the pairs in another arrangement differed only in tower location and finally another arrangement differed only in controller location. By then checking to see which of each pair the controller preferred, it was possible to assign a score of from +8 to -8 for each variable for each man. These scores were then seperately averaged for all local controllers and all ground controllers, and a test was made to see if they differ significantly from 0, i.e., no preference.

The local controllers showed no preferences for a particular orientation of the cab to the runway or for the nonparallel or parallel sided cab. They did indicate a preference for being at the intersection of two sides, as compared to being in the middle of a window, and this was significant at the .02 level of confidence. They also showed a strong preference for having the tower across the runway from the apron, and this was significant at the .001 level. It is important to note that the roof support in the mock-up tower cab is located almost in front of the simulated local control position. This represented an obvious interference with vision.

The ground controllers indicated preferences for the five sided cab, the middle of the window position and a flat part of the cab facing the active runway, but these preferences were at only the .10 level of confidence. There was no preference for the location of the tower.

Table 3-7

JOB RELATED IMPORTANCE OF TOWER CAB DESIGN FEATURES

Question	Mean	Rank
1. Presence or absence of tinted glass	.98	23
2. Large uninterrupted areas of glass	1.62	9
3. Tilt or outward slope of glass	1.12	21
4. Amount of floor space in tower cab	1.47	15
5. Number of sides in the tower cab	.55	24
6. All interior paint work of dark non-reflecting colors	1.39	16
7. Presence or absence of outside catwalk	.26	26
8. Presence or absence of permanent railing on outside catwalk	.51	25
9. Location of stairwell with respect to working area	1.07	22
10. Overall console design	1.78	6
11. Height of writing surface on console	1.33	17
12. Location of subject's assigned controllers position with respect to other controllers positions	1.76	7
13. Location of subject's assigned controllers position with respect to ASDE	1.21	20
14. Location of subject's assigned controllers position with respect to ASR	1.30	18
15. Height of tower cab above ground	1.55	11
16. Nearness of tower cab to runways	1.52	13
17. Ability to see both ends of active runway	1.94	1.5
18. Ability to see runway turn-offs	1.94	1.5
19. Ability to see taxiways	1.88	4
20. Ability to see run up areas	1.84	5
21. Ability to see ramp areas	1.50	14
22. Ability to see aircraft on final approach	1.90	3
23. Reflections on glass only in corners	1.28	19
24. Reflections on glass in locations other than corners	1.65	8
25. Location of visual obstructions	1.53	12
26. Number of visual obstructions	1.57	16

Table 3-8

DESIGN FEATURE PREFERENCE AS A FUNCTION OF

TOWER SHAPE

Question	Regular Octagon		Square Cab	
	Mean	P	Mean	P
1. Presence or absence of tinted glass	.789	N. S.	.85	N. S.
2. Large uninterrupted areas of glass	1.92	.001	1.62	.001
3. Tilt or outward slope of glass	1.14	N. S.	1.27	.05
4. Amount of floor space in tower cab	1.78	.001	1.38	.10
5. Number of sides in the tower cab	1.75	.001	1.36	.10
6. All interior paint work of dark non-reflecting colors	1.36	.01	1.60	.001
7. Presence or absence of outside catwalk	.86	N. S.	1.21	N. S.
8. Presence or absence of permanent railing on outside catwalk	.80	N. S.	1.17	N. S.
9. Location of stairwell with respect to working area	1.28	N. S.	1.00	N. S.
10. Overall console design	1.54	.001	1.38	.10
11. Height of writing surface on console	1.16	N. S.	1.00	N. S.
12. Location of subject's assigned controller's position with respect to other controller positions	1.08	N. S.	1.12	N. S.
13. Location of subject's assigned controller's position with respect to ASDE	.80	N. S.	.67	N. S.

Table 3-8 Continued

Question	Regular Octagon		Square Cab	
	Mean	P	Mean	P
14. Location of subject's assigned controller's position with respect to ASR	1.25	N.S.	1.50	N.S.
15. Height of tower cab above ground	2.00	.001	1.56	.01
16. Nearness of tower cab to runways	1.12	N.S.	.81	N.S.
17. Ability to see both ends of active runway	1.60	.001	1.17	N.S.
18. Ability to see runway turn-offs	1.60	.001	1.19	N.S.
19. Ability to see taxiways	1.48	.001	1.35	.05
20. Ability to see run up areas	1.46	.001	1.35	.01
21. Ability to see ramp areas	1.44	.01	1.29	N.S.
22. Ability to see aircraft on final approach	1.52	.001	1.29	N.S.
23. Reflections on glass only in corners	1.39	.01	.93	N.S.
24. Reflections on glass in locations other than corners	1.28	.10	1.31	N.S.
25. Location of visual obstructions	1.64	.001	1.67	.001
26. Number of visual obstructions	1.68	.001	1.69	.001

PROPOSED WINDOW WASHING SYSTEM

Section 4

The glass in the typical tower cab is cleaned by a local commercial window washing company whose contract with the FAA provides for both periodic and on-call service. Although this arrangement is usually quite satisfactory, there would be an obvious advantage if a capability existed for washing the glass quickly and automatically whenever required.

Of the alternative designs considered, a chemical cleaning system had the least complicated exterior mechanical requirements. In addition, a chemical system did not use rubbing components that would require periodic maintenance and replacement. Before such a system was proposed, however, it was felt that the concept should be given some preliminary tests.

To conduct these tests a window washing test stand was built outdoors at NAFEC. One pane of 1/2" thick, polished plate glass with a 70 square foot surface area was mounted in the test stand. The glass was inclined at 12 1/2 degrees, the slope of the windows in the proposed cab design. Chemical solutions were directed at the glass through ten commercially available spray nozzles. The nozzles were mounted in a common pipe, or manifold. The manifold could be manually rotated through an arc of 20 degrees. Three solutions, a prewash, a wash, and a rinse, were supplied to the spray nozzles by a motor driven pump that developed approximately 80 psi pressure. For the preliminary tests commercially available chemicals were used. The chemical solutions were mixed and stored in three open stainless steel tanks. To activate the chemicals it was necessary to heat the washing solution to approximately 160° F prior to a test. The outdoor temperature at the test stand was approximately 55° F.

Should a decision be made to pursue this work further, a prototype system could be fabricated, installed, and tested using the mock-up cab at NAFEC. A new chemical washing solution is desireable, one that does not require heating. If possible, the chemicals used should be injected into the water in a liquid form. The possibility of using this system to remove ice and snow should also be considered.

An hour prior to each test the glass was liberally daubed with lard and a mixture of powdered graphite and kerosene. In addition water based insecticide was also sprayed on the glass. Figure 4-1 shows

these materials applied to the glass prior to a test. Figure 4-2 was taken during a test run and shows the chemical solutions being sprayed on the glass. Figure 4-3 was taken at the end of the test. The three chemical solutions were supplied in sequence: pre-wash, wash, and rinse. This sequence was not interrupted or repeated during a test. The spray was moved up and down the glass by manually rotating the manifold that contained the spray nozzles.

Results

The initial tests indicate that the glass was successfully cleaned to a level within one foot of the top. Some residue did remain at that height.

The heated washing solution reacted with the outdoor temperature and produced an objectionable cloud of vapor.

FIG. 4 - 1 PRIOR TO TEST - GLASS DAUBED WITH A MIXTURE OF POWDERED GRAPHITE AND KEROSENE, LARD AND WATER BASED INSECTICIDE. MATERIAL PERMITTED TO DRY ON GLASS FOR ONE HOUR PRIOR TO WASHING

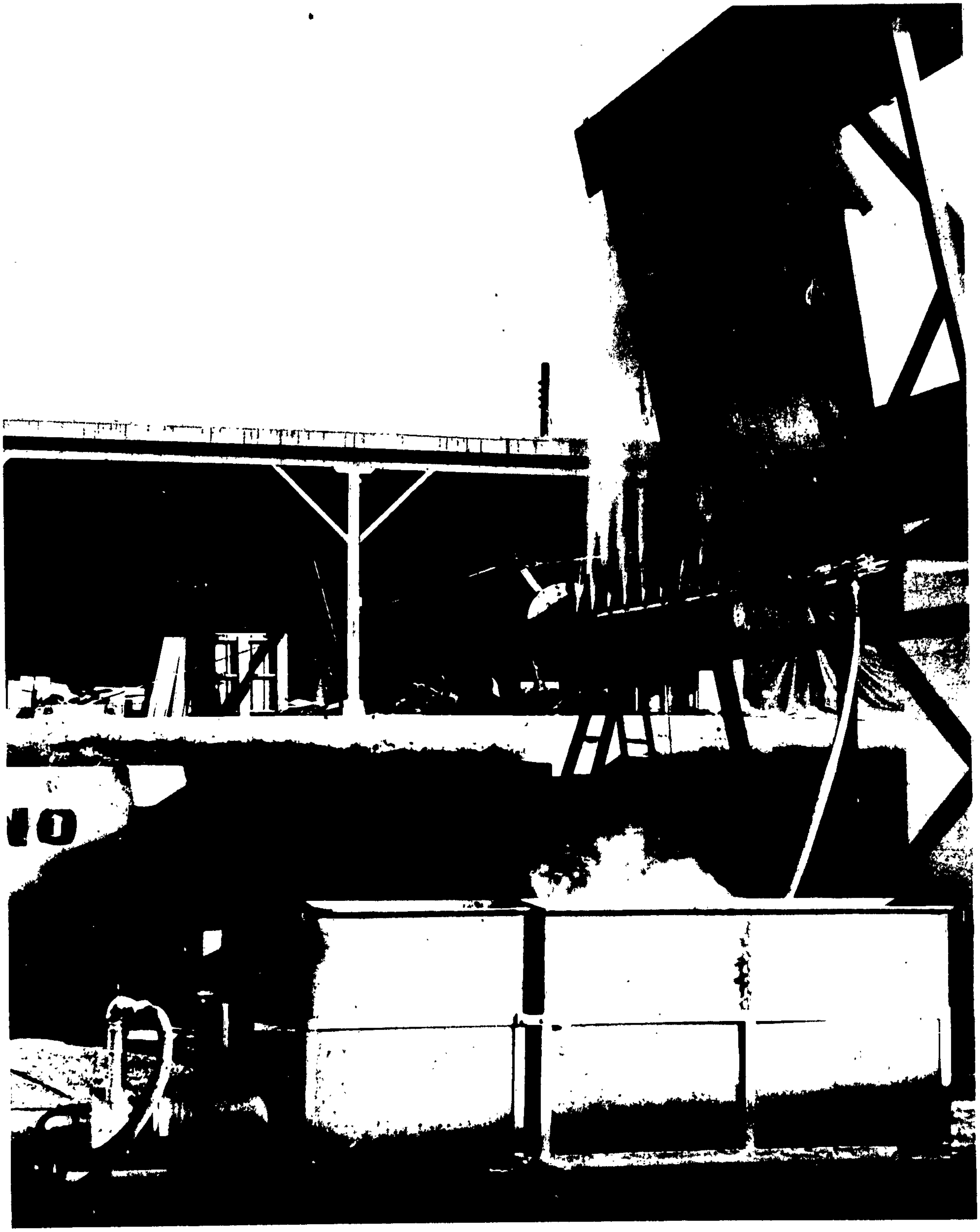


FIG. 4 - 2 PROPOSED WINDOW WASHING SYSTEM IN OPERATION - MOTOR DRIVEN PUMP AND CHEMICAL SOLUTION TANKS IN FOREGROUND

FIG. 4 - 3 RESULTS OF INTIAL TEST WITH PROPOSED WINDOW WASHING SYSTEM

CONCLUSIONS, RECOMMENDATIONS, & PROPOSED FUTURE WORK

Section 5

Conclusions

1. The upper one foot of glass is used sufficiently to justify its need.

2. An inclined ceiling will reduce light intensity significantly only if the angle is sufficiently large (20 degrees or greater). Due to floor to ceiling height limitations, it is not possible to incline the entire ceiling surface. If only a segment of the ceiling is inclined, the glass area adjacent to the ceiling should be darker. This area is not considered to be a problem area.

3. The ceiling should be made of a sprayed on, rough finish plaster that has acoustical damping properties. A bright ceiling, whether painted or internally illuminated, should not be considered.

4. The colors used in the mock-up had very low reflectance value and were acceptable to the controllers who participated in the opinion survey.

5. Objects that normally hang from the ceiling should be recessed.

6. The roof should be supported by several thin columns spaced around the periphery of the cab rather than by one large column.

7. As the slope increases the vertical height of reflections on the glass between corners is reduced approximately 1 inch per one degree of increased glass slope. The area of corner reflection is reduced slightly from 12 1/2 degrees to 17 1/2 degrees but is reduced significantly with a slope of 20 degrees. The angles of downward visibility are the same for 12 1/2, 15, and 17 1/2 degrees. The angles of upward visibility are decreased slightly as the slope increases from 15 to 17 1/2 degrees. The 12 1/2 degree slope provides several additional degrees of upward visibility on the immediate right and left of the controller, but the difference becomes progressively less as the bearing is increased. The largest reduction in upward visibility occurs

between 12 1/2 and 15 degrees. As the slope increases from 12 1/2 to 20 degrees, the largest decrease in upward visibility occurs at zero degrees bearing.

8. The use of single thickness glass reduces the number of visual obstructions by 67%. A ducted forced air system is required to prevent condensation from obscuring the interior glass surface.

9. The use of untinted glass permits a greater percentage of the available, visible light to enter the cab. Present commercial production standards are such that the glass must be untinted in order to transmit sufficient visible light in the thickness required for single sheet installation. The use of untinted glass presupposes the use of sunglasses by controllers. The eye pieces of binoculars should be redesigned so that they are usable while wearing a standardized, sunglass contour.

   The total solor energy transmitted by the conventional 1/4 inch thick tinted thermopane glass is approximately equal to that transmitted by 3/4 inch thick, untinted glass.

10. The use of specialized glass treatments, i.e., reflective coatings, curved glass, etc., is not considered necessary.

11. The overall console shape seems satisfactory to the controller subjects.

12. The interior lighting presently in the mock-up cab is usable only for maintenance purposes.

13. The floor covering should be durable, unpatterned, light diffusing material. The color should have a low reflectance value. The floor should never be waxed or polished. Carpeting, although good acoustical damping material, should be avoided since it is more difficult to clean thoroughly and would tend to collect dust.

14. It is important to reduce the amount of dust in the air in the tower cab. The dust that settles on the glass causes annoying specular reflections. Possibly, an electronic precipitation dust collector should be installed in the tower cab to remove the dust introduced by other than airborne sources.

15. The controller subjects had little interest in the catwalk around the outside of the tower cab. They apparently assume that if one were provided in the overall tower design, it would not reduce their downward visibility, and it would be equipped with a railing.

It is doubtfull if a catwalk would be of great use when replacing glass. The outward slope of the walls inhibits its usefullness. A catwalk is only required if manual window washing techniques are used.

16. It seems desireable to locate the rotating airport beacon on top of the tower cab. Its periodic flashes become annoying, especially in cabs equipped with non-tinted glass. The tower cab should be adequately insulated from the attendent motor and gear noises.

17. Controllers should wear dark colored shirts to reduce reflections.

18. The preliminary tests of the proposed semi-automatic chemical window washing system indicate that minor redesign work is required to satisfy the cleaning requirements. A washing solution that does not require heating is needed. Specifications for the completely mechanized system should be determined and the prototype installed and tested on the pentagonal tower cab.

19. The simulated local controller position used in the opinion survey was not satisfactory to the controller subjects. The arc of vision was interrupted by the roof support located just to the left of the simulated position. The dislike for the simulated position was shown in the opinion survey when individual local controllers indicated a preference for the corner position.

20. The elevation of the tower cab has a strong impact on the controllers performance. The high tower cab provides both a better airport panorama and a better perspective of objects on the ground.

Recommendations

1. The floor to ceiling height should be a minimum of ten feet.

2. The ceiling should be flat with provision for recessing those objects that normally hang from the ceiling. A sprayed-on, acoustical plaster should be the type of material considered.

3. The interior colors should be:

	Martin Senour Color
Columns and glass setting	#N-M-S-1
Ceiling	#M-S-2
Console and floor	#N-M-S-2

4. The glass slope should be twenty degrees.

5. Single-pane, untinted polished plate glass should be used if, and only if sunglasses and binoculars designed to be used with sunglasses are provided, and there use is incorporated in the standard operating procedures.

6. The floor covering should be a durable, light diffusing, unpatterned material in a color with a low reflectance value. Carpeting should not be used.

7. An electronic precipitation dust collector should be installed in the tower cab to remove that dust introduced by other than airborne sources.

8. Provide a semi-automatic system to wash and deice the cab windows.

9. Provide a catwalk around the tower cab until the semi-automatic window washing system has been thoroughly tested.

10. Controllers should wear dark colored shirts.

11. The concept that the ground controller's position should be at the point with the local controller located to the side should be investigated further before the operating positions are fixed.

12. The console design and location should be investigated.

Proposed Future Work

Console Design and Location

The location of the consoles in the tower cab and their overall design have a decided effect on the visibility from the cab. An investigation

is required to determine the controllers needs and his utilization of equipment contained in the console. The analysis of information gathered from such an investigation should provide insight into the possible redesign of the workspace. Proposed designs could be given a simulated operational test by testing them in the pentagonal cab at NAFEC.

Night Lighting Requirements in the Tower Cab

The activity in several operational towers should be observed to determine those controller activities that require lighting. Specially designed equipment could be built and tested in the pentagonal tower cab under simulated operational conditions.

The Geometric Shape of The Tower Cab

A research effort should be undertakne to attempt to determine the most desirable geometric shape for tower cabs. The mathematical work presented indicates that the area of corner reflection will not exist when the included angle between two sides is greater than 120 degrees. Possibly, some generalized principles could be found that would provide the required information.

The following is a proposal for the development of performance criteria or measurement yardsticks by which the effects and significance of visual obstructions could be measured. It was conceived by Dr. R. K. McKelvey in collaboration with Dr. E. P. Buckley.

Human Factors Performance Implications of Tower Design Variations

To the present, this project has devoted attention to the effects of tower design characteristics on visual obstacles like ceiling reflections and glare. The effort has been to determine the design variations which minimize visual obstacles. Further work could, and probably should, be done along these lines. However, it would be extremely prudent before proceeding to develop performance criteria or measurement yardsticks by which the effects and significance of such visual obstructions could be determined.

If these visual obstructions affect system effectiveness, they must do so by affecting controller performance. This effect might take the form of direct task interference, i.e., a certain probability

that the controller might not see something in the environment that he needs to see in order to control the traffic. On the other hand, the controller, by putting forth extra effort, might overcome or compensate for these visual obstructions or annoyances. This extra effort may be a system cost, however, which could, over the course of hours, create controller visual fatigue, or even a generalized fatigue, with consequent increased likelihood of error and reduced ability to tolerate system stresses.

It is completely unknown at present whether the visual impediments which might result from tower cab design features have any of the above effects. Perhaps, the effect on the controller is so minimal than any further attention to tower cab design should be confined to aesthetic and cost reduction considerations. On the other hand, it is possible that the visual environment has such pronounced effects on controllers that system safety is jeopardized. In any event, it would appear to be of central importance to determine in which direction we ought to be most concerned.

A beginning can be made with an experimental effort in the Human Factors Research Branch Visual Task Laboratory. In the experimental task situation, controllers will be given a visual detection task under conditions of no visual obstruction and under visual obstruction conditions (of the type we have found might exist in tower cabs), and the results compared both in terms of visual task performance and physiological stress reactions.

There are many details to be worked out in the course of implementing an experimental program of this nature, but its general outline can be indicated. There are three basic categories to consider:

(1) Creating the Obstruction Conditions

(2) The Visual Task

(3) Performance Measurement

(1) Creating The Obstruction Conditions

To create glare in the laboratory is a simple matter. The controller subject can stand behind a piece of glass, and the amount of glare and reflection to which he is subjected can be manipulated by appropriately illuminating the glass in a controlled manner. No

extensive tower cab mock-up is required. Obstructions like mullions and joints can also be simulated simply.

(2) The Visual Task

The tower controller's visual task is basically one of detection and identification of aircraft. For the present purpose, almost any visual task requiring these two functions could be used. Based on considerations of economy and controller comfort in the situation, the visual task can be made more or less operationally realistic. At the extreme of non-operational tasks, one might ask the controller to pick the X's out of a display composed of a grid of letters, or to read the letters formed by hue and brightness gradients in Ishahara color plates. At the other extreme, one might have model aircraft moving along and across runways. An intermediate approach would be a slide-projected picture of an airport surface and sky with certain aircraft at various locations to be detected and identified. Another alternative already available is the model aircraft and variably illuminated surround already present and used as visual test objects in the Visual Task Laboratory in studies of aircraft conspicuity.

(3) Performance Measurement

As indicated above, visual performance basically will be measured by means of the percentage of correct and incorrect detections and identifications controllers make under the various conditions of glare. For example, suppose a slide of an airport is presented. The controller task might be to count the number of aircraft on the active runways and the number of aircraft waiting to enter the active runways, or he might be asked to locate aircraft in the landing pattern. The percent correct and incorrect would be counted. The questions to be answered by the experiment are: Does such detection performance decline with time in the task? Is the decline greater when glare is present? How much greater? For how much glare? (i.e., magnitude of the window area affected). These measurements would be made over the course of a two-hour simulated "watch."

It is just possible that actual visual performance might not decline, i.e., the controller might compensate by an effort which would get him the same results at a greater cost in visual and general fatigue. It is for this reason that merely measuring the visual performance would be an inadequate measurement; it is the hidden cost in visual and general fatigue which must also be counted. Methods have

recently become available which would seem worth intensive exploration as sensitive methods of determining the amounts of visual and general fatigue which result from the performance of a given task under various environmental conditions. These measurements will be taken along with the performance measurements. Among them are electromyographic muscular tension, psychogalvanic skin responses, and critical flicker frequency.

While it is not considered as thoroughly established, many authorities feel that these measures vary directly with fatigue and stress. Thus, they might indicate the reserve the controller has left for response to emergencies or sudden increments in workload. They have been explored as indices of this sort many times in the past and are regarded as definitely worth trying as concomitant measures to see what they reveal about workload tolerances in this situation. For this purpose, the degree of covariation of such indices with frequency of overt error will be analyzed.

SUMMARY

To sum up, it is important, before further work is done on tower design, to determine the effect of tower design on controller visual performance and fatigue. An experimental method which can be implemented shortly is suggested to determine these facts.

APPENDIX A

MATHEMATICAL FORMULA FOR DETERMINING THE HEIGHT REFLECTIONS LOCATED BETWEEN CORNERS

J. R. Vander Veer

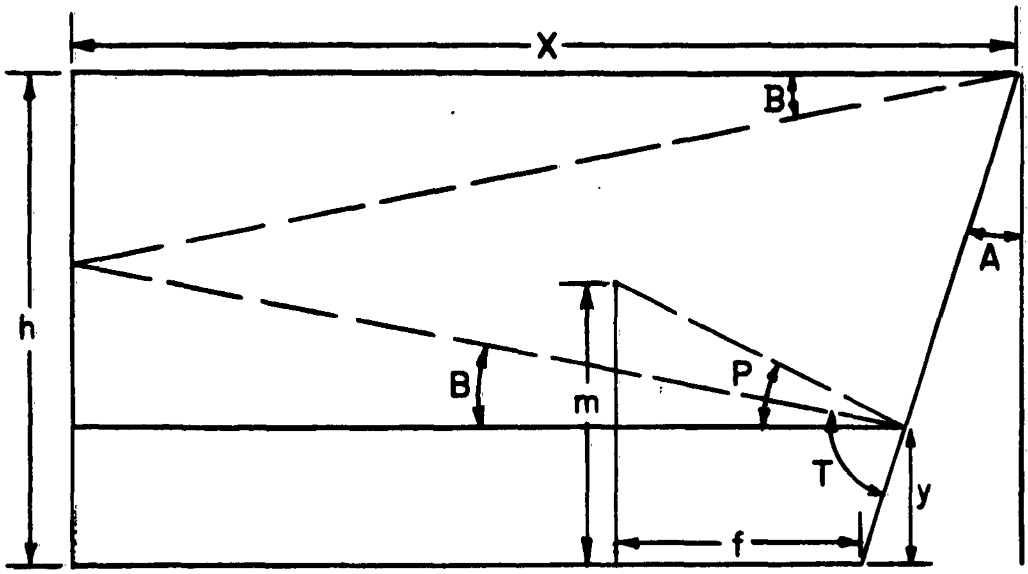


FIG. 1

Given information on dimensions of a control tower, the eye level of the controller, and the distance he stands from the window, the problem is to determine the height of the glare on the window. This glare area results from light entering the rear of the control tower.

The problem may be considered to be the same as determining where a ray of light entering at ceiling level will strike the window and be reflected into the controller's eye. Figure 1 is a diagram showing light entering at the ceiling, being reflected by a perfect reflector at the center of the cab, then being reflected by the window into the controller's eye. This is the same problem if we consider the light entering the rear of the cab.

The point on the window where the light strikes is the maximum height that glare will appear on the window for the given conditions.

The problem is to determine the glare height y as a function of X, h, f, m, and A where:

X = length from edge of roof to center of the cab

h = height of the cab

f = distance controller stands from the window

m = eye level of the controller

A = slope of the glass measured from the vertical

Referring to Fig. 1 it is possible to write the following two equations in terms of two unknowns y and Tan B.

1. $h = X \operatorname{Tan} B + (X - h \operatorname{Tan} A + y \operatorname{Tan} A) \operatorname{Tan} B + y$

2. $m = (f + y \operatorname{Tan} A) \operatorname{Tan} P + y$

Solving equation 1 for Tan B we obtain

3. $$\operatorname{Tan} B = \frac{h - y}{2X - h \operatorname{Tan} A + y \operatorname{Tan} A}$$

From Figure 1 we also see that

4. $T = B + 90^{\circ} - A$

And remembering that the angle of incidence equals the angle of reflection, we see that

5. $P = 180^{\circ} - 2T + B$

And substituting for T find that

6. $P = 2A - B$

Substituting (3) and (6) into equation (2) and performing the necessary substitutions and algebra we obtain the function

$$y = (2Xm + fh + (nm - 4Xf) \operatorname{Tan} A + (fh - 2Xm) \operatorname{Tan}^2 A + hm \operatorname{Tan}^3 A) \div (2X + f + m \operatorname{Tan} A + (2X + f) \operatorname{Tan}^2 A + m \operatorname{Tan}^3 A)$$

As an expression of the vertical height from the floor that glare will appear on the window

APPENDIX B

MATHEMATICAL FORMULA FOR DETERMINING THE AREA OF CORNER REFLECTIONS

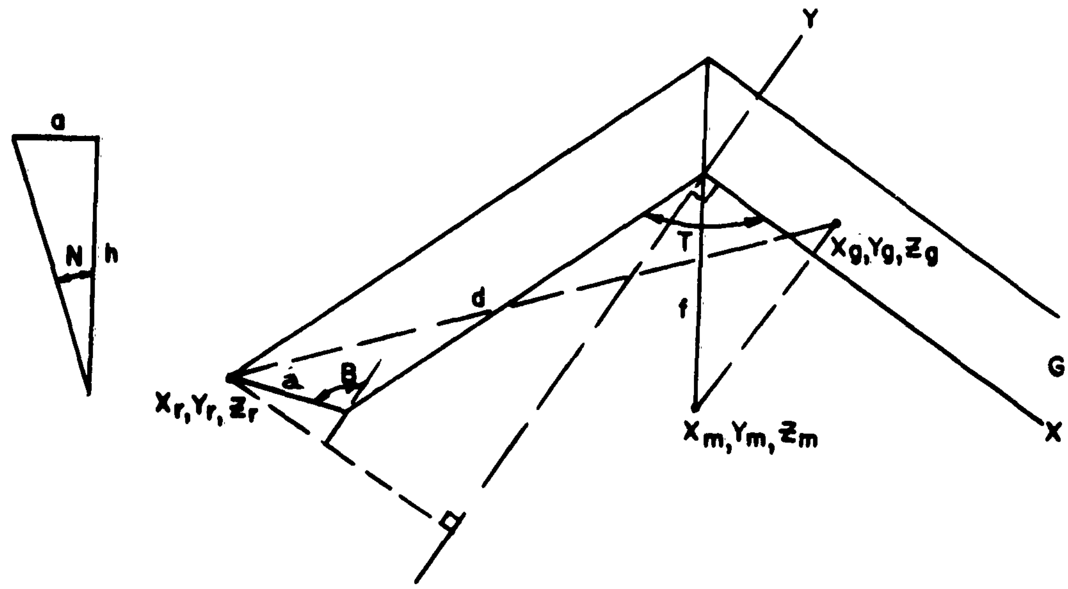


FIG. 2

The problem of determining the glare area attributable to the adjacent window in a control tower resolves into the problem of determining the point (X_g, Y_g, Z_g) in the plane of the glass where a ray of light entering at the far corner ceiling (X_r, Y_r, Z_r) will impinge and be reflected into the eyes of the controller at X_m, Y_m, Z_m. Once knowing this point, the area of glare, as seen by the controller, can be determined.

Since the angle of incidence is equal to the angle of reflection, the problem may be resolved further to that of finding the intersection of the line connecting (X_r, Y_r, Z_r) and the mirror image of X_m, Y_m, Z_m) with respect to plane F, with the plane G.

The first step is to define the points (X_r, Y_r, Z_r) and X_m, Y_m, Z_m) in terms of the given parameters:

a, d, h, m, f, T, and N

where d = cab wall length measured at the floor.
h = height of cab.

m = eye level of the controller.
f = distance controller stands from the window intersection.
T = angle formed by the adjacent sides of the cab.
N = angle of the glass measured from the vertical.

From Figure 1 we see that:

1. $a = h \tan N$

2. $B = (180 - T) + \frac{T}{2} - (T - 90)$

   and so, $B = \frac{540 - 3T}{2}$

3. Knowing B, we may proceed as follows:

4. $X_r = d \text{ Sin } (T-90) + a \text{ Sin } B$

5. $Y_r = d \text{ Cos } (T-90) + a \text{ Cos } B$

6. $Z_r = h$

7. $X_m = f \text{ Cos } T/2$

8. $Y_m = f \text{ Sin } T/2$

9. $Z_m = M$

Having defined the points with respect to a system having the X, Y plane as the floor of the cab, the next step is to express the points with respect to a coordinate system having the x, y plane as the window on which the glare appears, the origin at the point where the adjacent sides and the floor meet.

The points (X_r, Y_r, Z_r) and (X_m, Y_m, Z_m) may be defined in the new coordinate system by the following transformations:

10. $x = X$

11. $y = Y \text{ Sin } N + Z \text{ Cos } N$

12. $z = -Y \text{ Cos } N + Z \text{ Sin } N$

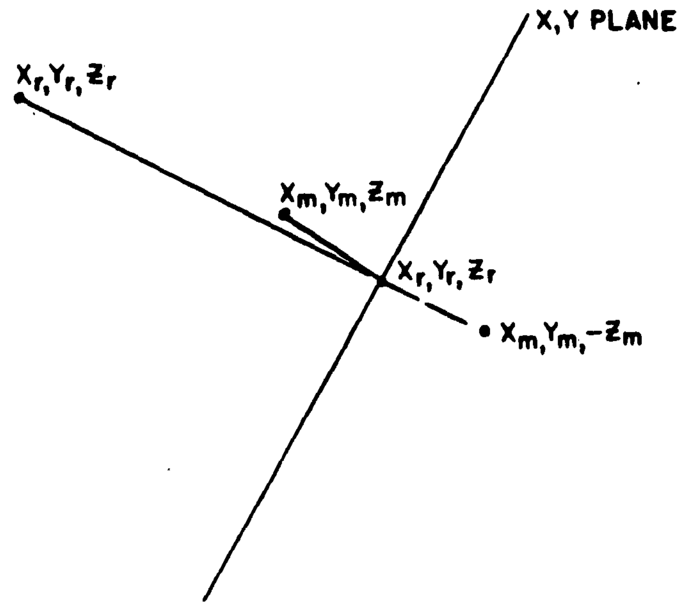


FIG. 2

From figure 2 we see that the problem is now to find the intersection of the line connecting point (x_r, y_r, z_r) and the mirror image of (x_m, y_m, z_m) or $(x_m, y_m, -z_m)$ with the plane G.

We can write the relation

12 $$\frac{x_r - x_m}{z_r - (-z_m)} = \frac{x_r - x_g}{z_r - z_g}$$ and solve for x_g

yielding

13 $$x_g = \frac{x_r\, zm + x_m\, z_r}{z_r + z_g}$$

similarly

14 $$y_g = \frac{y_r\, z_m + y_m\, z_r}{z_r + z_m}$$

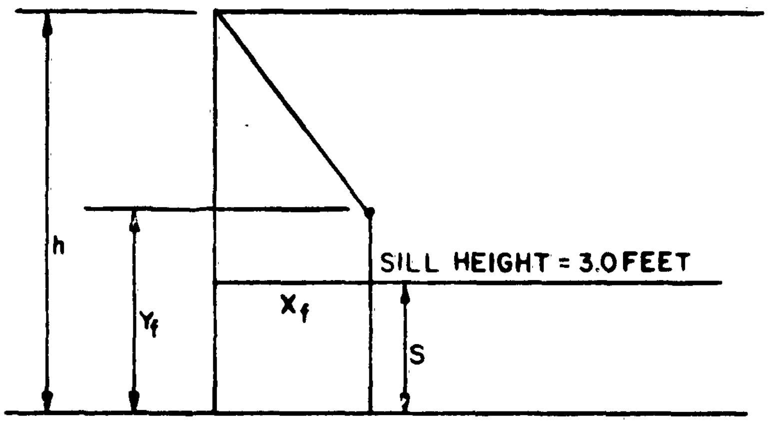


FIG. 3

The area of glare seen by the controller would be as shown in Figure 3. This is the projected area which would appear in a plane normal to the controllers line of sight.

The glare area A_g is defined by the equation:

$$A_g = (h - y_f)\frac{X_f}{2} + (y_f - S)\,X_f$$

where from Figure 4 we can see that

$$y_f = y_g \operatorname{Cos} N$$

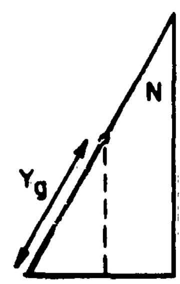


FIG. 4

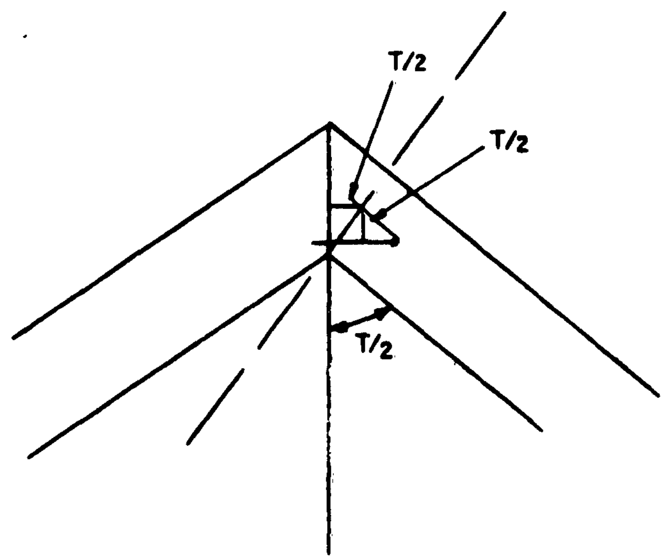


FIG. 5

and from Figure 5 that

$$X_f = X_g \text{ Sin } T/2 + y_g \text{ Sin N Cos } T/2$$

APPENDIX C

REPORT OF THE CONSULTANT ILLUMINATING ENGINEER, L. W. HORNFECK

SURVEY AND REPORT

OF

LIGHT TRANSMISSION AND REFLECTION CONSIDERATIONS

FOR

AIR TRAFFIC CONTROL TOWER CAB DESIGN

(Final Report)

TASK ORDER NO. 1
PROJECT 101-910 R
September 1962

Lawrence W. Hornfeck, P.E. (Editor)

"This report has been prepared by Lawrence W. Hornfeck, P.E. Consulting Electrical Engineer, for the Systems Research and Development Service, Federal Aviation Agency under Contract No. FAA/SRDS-N3-12. The contents of this report reflect the views of the consultant, who is responsible for the facts and for the accuracy of the data presented herein. The contents do not necessarily reflect the official policy of the F.A.A."

PREPARED

FOR

Systems Research and Development Service
National Aviation Facilities Experimental Center
Federal Aviation Agency
Atlantic City, New Jersey

BY

Lawrence W. Hornfeck P.E.
Consulting Electrical Eng.
711 Penn Avenue
Pittsburgh 22, Pennsylvania

CONTENTS

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Mr. T. H. Green, Systems Research and Development Service,
F. A. A. Project Manager

SUMMARY

The National Aviation Facilities Experimental Center, Atlantic City, New Jersey, is currently conducting experiments with a pentagonal shaped Air Traffic Control Tower Cab. The purpose of these experiments is to evaluate the design proposed, and to establish recommendations which would closely relate the physical design to the human activity demanded by the nature and purpose of the cab.

The purpose of this report is to present an analysis of the cab design as related to the visual functions required. This analysis shall provide guidance and recommend parameters within the limits of the present state of the art of illumination.

In particular such items as type, tint and slope of window glass, light transmission and reflection through and within the cab, and instrumentation for illumination comparisions are to be considered.

INTRODUCTION

In order that tower cab operators perform their functions efficiently, their physical needs must be provided for and one of the most important is the need to see without strain or obstruction. Any hindrance to an operators vision impresses a strain which shortens and impairs his physical and mental capabilities.

The major impediment to normal vision is the reception of light, at the point of observation, from sources that are not intended to be viewed. This light reaches the point of observation by reflection and appears as an image through which the operator must view. In addition to being distracting, the light from the reflected image may be of such intensity so as to be uncomfortable to the observer. This uncomfortable intensity is described as glare.

The purpose of this analysis is to determine just how these reflections can be eliminated or controled and what effect the control will have on the design of the Tower Cab.

BASIS OF COMPARISONS

To eliminate or reduce internal glass reflections, the light sources to be controlled must first be identified. There are two main light sources to be considered:

(1) the internal cab lighting fixtures

(2) the daytime sky

The point of observation should also be established. Unrestricted visibility from the tower cab is desirable, but in practice there are limits

set by cab construction, personnel task assignments, and the human physical dimensions.

The tower cab under study is of pentagonal shape, and with a vertical window inclination of 12-1/2° sloping up and out from the floor level. The ceiling height is 10'-0". The Air Traffic controller and the Ground Traffic controllers shall be positioned in or near a corner.

Since all tower cab operators are not of the same height, an average height of eye above the floor shall be used in this discussion. [1] It has been determined that, excepting for 5% of the tallest and shortest, the eyes of the American male will fall within a band between 61 to 71 inches above the floor. For purposes of simplification, the average of this band, 66 inches, shall be used and will be called the Point of Critical Vision.

[1] The operator, because of his visual task requirements and physical capabilities, is restricted but not limited to a vertical visual angle of 30° above and below the horizontal.

INTERNAL WINDOW REFLECTIONS - GENERAL

Internal window reflections can be described as images of the cab ceiling, ceiling lighting fixtures, personnel and cab equipment that appear on the window and in the operators line of vision. These images are caused by either daylight, or light generated within the cab. In either case the light strikes the ceiling, the personnel, and cab equipment and is reflected. A part of this initial reflection travels to the window glass and is again reflected back into the cab and toward the operator.

The images become apparent when the intensity of the light reflected

from the window is near or greater than the light coming in from the exterior scene being viewed. This situation becomes most pronounced during the hours of darkness, when the exterior light intensity is almost nil and the interior of the cab is lighted. Control of the intensity and direction of reflection is then the means to a solution.

NIGHT TIME REFLECTIONS

The night time light source can be controlled in several ways. First, the intensity of the ceiling lighting fixtures can be controlled by a dimmer which would be manually operated to adjust the light to an effective intensity. Full brightness would be available for cab maintenance or cleaning. A limit is set on this approach because the operators must have sufficient light by which to read and write.

A second control is the selection of lighting fixtures. The fixture should be of such a type that no light is emitted directly to the ceiling or toward the windows. The fixture should be recessed and have a light distribution characteristic curve that provides maximum horizontal shielding. The fixture type recommended would be similar to Lightolier Catalog No. 7762, and is illustrated in the appendix at the rear of this report.

A third control is the positioning of the lighting fixtures on the ceiling at locations which provides illumination for main traffic walkways. Console illumination should be provided on the console and have maximum shielding.

A fourth control is to incline the window glass at such an angle that reflection paths originate at directions where little or no light is generated, and place reflections at locations of least interference.

This variation in design affects both night time and daytime considerations and shall be fully appraised in the following discussion.

ANGLE OF WINDOW WALL INCLINATION

The foregoing discussion has suggested that the window wall be inclined to align light ray paths to the point of critical vision with sources of little or no intensity. Figures 1 through 5 inclusive show light ray plots for window wall inclinations at 10°, 12.5°, 15°, 17.5° and 20°. Each plot shows the path light must travel in order to terminate at the operators point of critical vision.

There are 3 areas of change to be noted. As the window wall is swung through its arc from 10° to 20°:

1. The area of ceiling reflection on the window increases.
2. The area of external sunlight or daylight reflections on the window decreases and what ever remains is depressed toward the lower limit of the window.
3. The operators own image is depressed toward the lower limit of the window.

The question is then: which is the optimum angle? Both the day time and night time conditions should be considered. It has been previously suggested that for night time operation, recessed shielded ceiling lighting fixtures be used to eliminate the light source at the ceiling. For day time conditions, we cannot control the sky but we can reduce the sunlight or daylight reflections on the window being viewed by increasing the angle of inclination.

It can be seen from the plots that at 20° inclination, sunlight

reflections remain and that further inclination ir required to eliminate it entirely.

TOWER CAB CEILING VARIATIONS

The problem related to this approach is concerned with reflections from the upper window of light being reflected from bright ceiling surfaces. The light sources providing light to this ceiling area are the floor of the cab and the ground area surrounding the tower. Several types of ceiling construction are plotted and shown on figures 7 through 10 inclusive. It can be seen that with any type of ceiling construction, there is always an angle of light coming from the floor of the cab. It follows then that the only means to eliminate or reduce these lines of light is at the floor itself by using materials with surfaces of low reflectance.

The outside light that is directed at the ceiling will be from roof tops of surrounding buildings, ground pavement, and snow. In the foregoing discussion, it has been suggested that a flat ceiling finish be used in order to reduce specular reflection (light reflected at an angle equal to the angle at which it strikes the surface). We are then dealing with a diffuse surface which if "perfectly" diffuse, will reflect light at relatively equal intensities at all angles from the surface. In general practice, however, surfaces are not made perfectly diffuse so that a specular component is almost always present and the average surface brightness will vary in accordance with the angle viewed. For a perfectly diffuse surface, the average brightness is governed by the cosine law which is illustrated by figure 6. This shows that for a given source intensity, the average surface brightness will decrease

as the light source is varied from a perpendicular to the lighted surface. The table of cosines shows also that the greatest decrease will occur throughout angles 45° to 90°.

Figures 7 through 10 show several ceiling constructions and the ceiling angles possible within the limits of the pentagonal cab.

Figure 7. With the ceiling sloped up to the window:

1. A great range of vertical visibility is possible.
2. The average angle of ground light strikes the ceiling at an indicent angle of 40°.
3. A moderate amount of ceiling area can be seen by window reflection.

Figure 8. With the ceiling sloped down to the window:

1. Vertical visibility is the same as that of a horizontal ceiling of the same window slant.
2. The average angle of ground light strikes the ceiling at an incident angle of 50°.
3. The full ceiling area can be seen by window reflection.

Figure 9. With the ceiling partially sloped up to the window:

1. A great range of vertical visibility is possible.
2. The average angle of ground light strikes the ceiling at an incident angle of 30°.
3. Amount of ceiling area reflection is not affected.

Figure 10. With the ceiling partially sloped down to the window:

1. Vertical visibility is decreased.

2. The average angle of ground light strikes the ceiling at an incident angel of 65°.
3. Amount of ceiling area reflection is not affected.

Conclusions:

The ceiling design shown in figure 10 is the design approach which tends to reduce ceiling brightness at the window. In view of the foregoing, it should be stated at this point that consideration of a luminous ceiling in the tower cab, for purposes of reducing the interior to exterior light ratios, is a step in the opposite direction. In order to reduce window reflections, the ceiling brightness must be reduced.

CAB CONFIGURATION - CORNER REFLECTIONS

A major area of daytime internal reflection is the area of window adjacent to a corner. These reflections are observed on days with sky conditions of bright sun or thin clouds and bright overcast. They appear as bright triangular shapes, with an apex at the ceiling and a base near the sill.

This area of reflection will vary in intensity, depending on the sky conditions. At high intensities this reflection becomes uncomfortable to view and obstructs normal viewing through the window. In this report, this area of reflection shall be called the "Area of veiling glare".

The nature of this glare is much the same as that of the bright ceiling adjacent to the window. In this case, instead of a bright ceiling, we have a sky of much higher intensities. The triangle is a reflection of the sky with the outside edges of the triangle being formed by the roof line of the adjacent window wall.

The base width of the area of glare is a function of the horizontal corner angle, the vertical inclination of the window glass and the position of the observer.

To simplify the geomety of the problem, we shall first analize the corner reflections of vertical window glass. In figures 11, 12, and 13, an observer is positioned on a line bisecting the corner angle. As the corner angle is increased, the reflection of the adjacent wall is decreased and in a direction towards the corner. When the sum of the angles of incidence and reflection is less than one half of the corner angle, no reflection of the adjacent wall can be seen.

Figures 11, 12, and 12 show only the area of brightness on the right window. The left window would be similar but of opposite hand.

It can be seen from figures 11 and 12 that as the observer moves to the right, more of the adjacent wall will be seen by reflection. Figure 13 shows that adjacent window wall reflections are viewed only when the observer is moved to the extreme right.

Figures 14 through 19 inclusive show light ray plots for window corners with sloping glass. These plots are approximations and are intended only as an illustration of reflection characteristics encountered as the corner angle is increased and as the window inclination is increased.

An experiment was conducted to observe the trend suggested by the light ray plots. Models were made of 90° and 108° corners, with window inclinations of 12.5°, 15°, and 17.5°.

An evaluation of the light ray plots and the experiment shows, in

general, that to reduce the area of veiling glare, the corner angle and the window inclination should be as large as is possible.

INSTRUMENTATION

The solution to a glare problem is complicated by the fact that glare is basically a personal response. Therefore it has always been difficult to establish set standards for glare comparisons.

(3) While field teams, of the Illuminating Engineering Research Institute were conducting studies on the amount of light required for effective seeing, a meter was developed that could be applied to the glare problems encountered in air traffic control tower design. This meter is called a "Disability Glare Meter" and was perfected by the Research Institute as a result of previous studies conducted by Dr. Glenn A. Fry, director of the Ohio State University School of Optics and Dr. Benjamin S. Pritchard of the Institute for Research in Vision, Columbus, Ohio.

In the course of work on the disability glare meter, a second more portable instrument was devised which could be applicable on control tower design to set local illumination levels. The meter is called a "Portable Visual Task Evaluator".

It is believed that this instrument might be utilized to advantage in gaining statistical data to further verify the findings of this report.

CONTROL TOWER CAB WINDOW GLASS

There is a twofold purpose for window glass in a control tower cab. First, the operator must be provided with an unobstructed and undistorted view of the field of his responsibility and second; the operator must be

protected from the elements of Nature. As fundamental as this statement may be, it shall provide a basis for the evaluation of window glass in this report.

The choice of window material will then be governed by the extent to which each material can satisfy the two basic needs without serious compromise to either of the two.

The two fold purpose of window glass can be translated into technical language by stating that (1) unobstructed, undistorted view = visible light transmittance. (2) protection from the elements = infra red transmittance = BTU heat gain.

The glasses under consideration for the subject project are (1) clear polished plate, (2) tinted polished plate and (3) double glazed hermetically sealed with one panel tinted.

Figure 20 in the appendage of the rear of this report lists the transmittance characteristics of various glasses, presently available, from which the following observations can be made.

Clear polished plate transmits the maximum visible light but it also transmits the maximum solar energy.

Glass is tinted to intercept solar energy but by doing so, the transmission of visible light is reduced.

In a cab using clear polished plate, maximum visible light and solar energy are transmitted into the cab. The visible light is usable but the solar energy strikes the surfaces of the cab and increases the ambient temperature of the cab. While the cab temperature can be regulated by

air conditioning equipment, solar energy strikes the operator and causes a discomfort which cannot be eliminated by air conditioning. While it is true that the clear glass has the greatest heat loss, under winter time conditions, the ambient cab temperature will reach levels that require regulation by air conditioning. Water vapor must be removed from the internal atmosphere in order to prevent condensation on the cold glass. An adequate air conditioning system is then the main factor in achieving a reasonable design with clear glass. However, the operator is left unprotected from direct solar energy.

By using 1/4" tinted plate, up to 55% of the objectionable solar energy can be intercepted and yet maintain the visible light transmission level at 75% which is above present standards set by F. A. A. Tinting the glass provides for the operators protection but does not reduce heat loss during winter time operation, and would reduce air conditioning requirements for summer time operation only.

The next step is to reduce heat losses through the window. This can be done by double glazing, that is by using an outside panel of tinted glass and an inside panel of clear glass. The two panels would be separated by a sealed, dry air space. This treatment would reduce the heat transmission through the window wall, and reduce the tendency of water vapor to condense on the window wall.

RECOMMENDATIONS

Analysis of the problems presented in the foregoing indicate significant trends. Based on these trends, this report makes the following recommendations:

1. The inclination of the window wall should be not less than but equal to or greater than 15°.
2. The configuration of the cab should be that geometric figure which allows the largest horizontal corner angle possible.
3. The ceiling design should be horizontal with a segment sloped down to the window.
4. The window wall should be double glazed with the exterior panel tinted and the interior panel clear.
5. The ceiling should be painted in dark colors of flat finish and low reflective surface.
6. The floor should be covered with carpet of dark colors.
7. Tower cab personnel should wear colors other than white.

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Combined report No. 53, FAA/BRD 390, Project CC
by Courtney and Company, Philadelphia, Pennsylvania

(2) Pittsburgh Plate Glass Company
Light transmittance chart - January 1962.

TRANSMITTANCES

Product	Thickness	Visible Light	Infra Red	Total Solar Energy
Polished Plate	3/8"	86	56	70
Polished Plate	1/2"	85	49	65
Polished Plate	3/4"	82	39	59
Solex Plate	3/8"	67	11	34
Solex Plate	1/2"	60	(This glass is not available as a regular production item)	
Solex Plate	3/4"	49		

FIGURE EXPLANATIONS

In general, only one half of the tower cab is shown, in the sections. The second half would be similar but of opposite hand. The dashed lines are identified as light ray plots and indicate a line of direction that light must travel to reach the point of critical vision.

During the day, light enters the cab, through the window as direct sunlight or light diffused by the clouds. The direct ray will strike the floor, or any surface in its path and is reflected. The direction the reflected light takes will depend on the surface it strikes. If the surface is smooth, most of the light ray will be reflected at an angle which is equal to the angle the original ray makes compared to a perpendicular to the surface. This part of the reflection is described as specular. Part of the initial ray will be reflected about at all angles at varing intensities. This part of the reflection is described as diffuse. Therefore this point of reflection can be seen from all angles about the point. The countless rays entering the cab are reflected in the same fashion. The initial impact surface is then illuminated by this scattering of light. The reflected light continues traveling until it collides with, and illuminates another surface. The intensity of a light ray is not constant through out its travel but decreases to an intensity which is inversely proportional to the square of the distance traveled.

In figures 1 through 5 inclusive, the intensity of the light is not an immediate consideration. The line plots show the observer at the point of critical vision and the lines of sight which will receive light coming from particular parts of the ceiling.

As shown then, the light travels to the window and is reflected from the glass to the observer. It follows then that a particular point on the ceiling will appear at a particular point on the glass. The figures show the change of position on the glass of the ceiling image as the angle of window inclination is varied.

The light rays coming, into the cab, through the opposite window are shown traveling through the cab and striking the window being viewed. While most of this light will pass through the window being viewed, a portion of the light will be diffused and be reflected at specular and random angles and cause an illumination of the window being viewed.

Figures 1 through 5 inclusive, show that as the angle of window inclination is increased, the area of glass covered by ceiling reflections increases, and the area of glass covered by direct external light reflections decreases.

The intensity of the direct external light is greater than any reflected light from the ceiling due to the nature of the distances traveled and surfaces

encountered. Therefore, the reflections of direct external light are the most objectionable and can be reduced by using the maximum window inclination possible.

FIGURES 11, 12 and 13

These three figures show the reflection characteristics of vertical wall window glass corners.

The dashed line plots show the path of light coming through the left window and being reflected to an observer. In all cases, distance BC is equal.

Figure 11 shows a 90° corner. Light comes through point C and appears to the observer at point E. When the observer moves to point F, point C will appear at point G.

Comparing figure 11 with 12 and 13, it can be seen that as the corner angle opens, and for a given position, the image of point C on the right window moves cleser to the corner.

FIGURE 14

Light from the ceiling at points A, B, C, and D is reflected from the right window and appears to the observer at points E, F, G, and H. The unshaded area on the right window indicates the area on which ceiling reflections appear to the observer. The shaded area on the right window indicates the area on which direct external light reflects and appears to the observer. In figures 16, 17, 18, and 19, the same method of presentation is used.

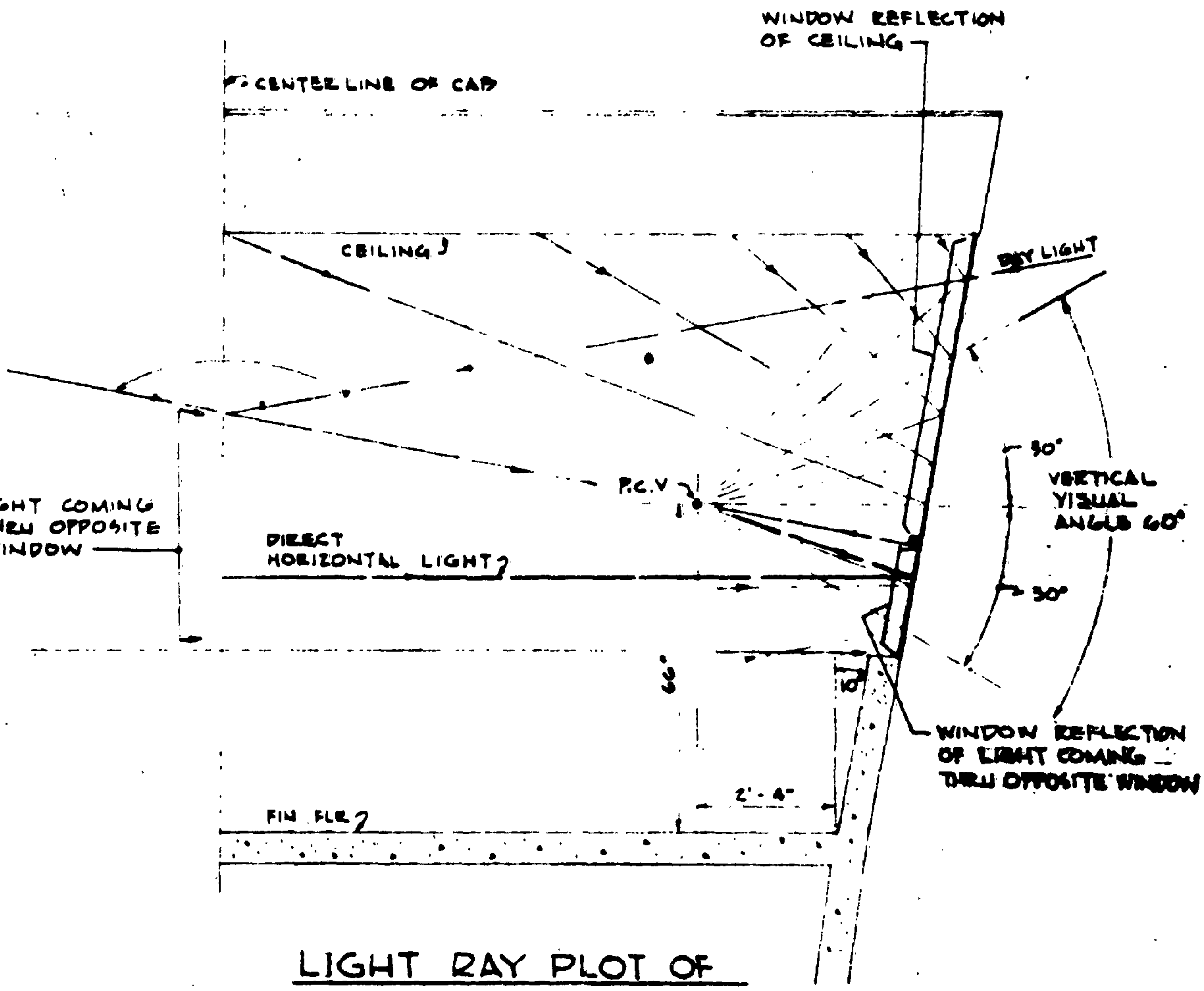
THE COSINE LAW

The cosine law, as related to illumination can be stated as follows: The intensity of perfectly diffuse light is proportional to the cosine of the angle of incidence.

In Figure 6, the line of light is shown as though entering a cab at an angle of 45°. This angle is used as an average angle of light being reflected from the ground to the cab. Every angle between vertical and horizontal is a possibility. This average line of light is shown striking a ceiling, which is placed at horizontal, 10°, 20° and 30°. The angle of incidence is shown in each instance.

The formula stated at the bottom of figure 6 is read as follows:

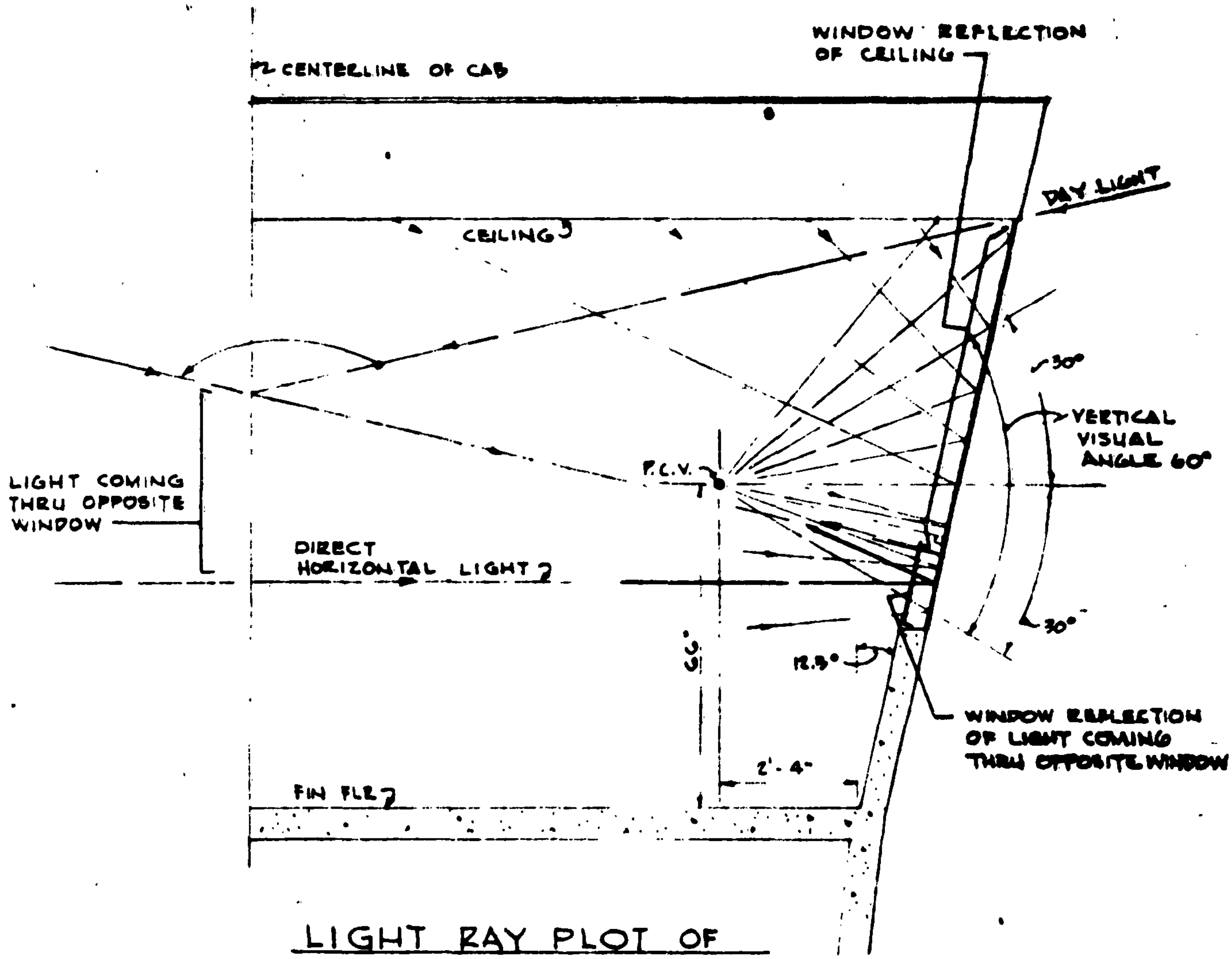
The intensity of any ray of light reflected from the point of incidence (I theta) is equal to the product of the intensity of the incident light (I 90°) and the cosine of the angle of incidence (Cos theta).



LIGHT RAY PLOT OF
WINDOW SLANTED 10°

SCALE: 3/8" = 1'-0"

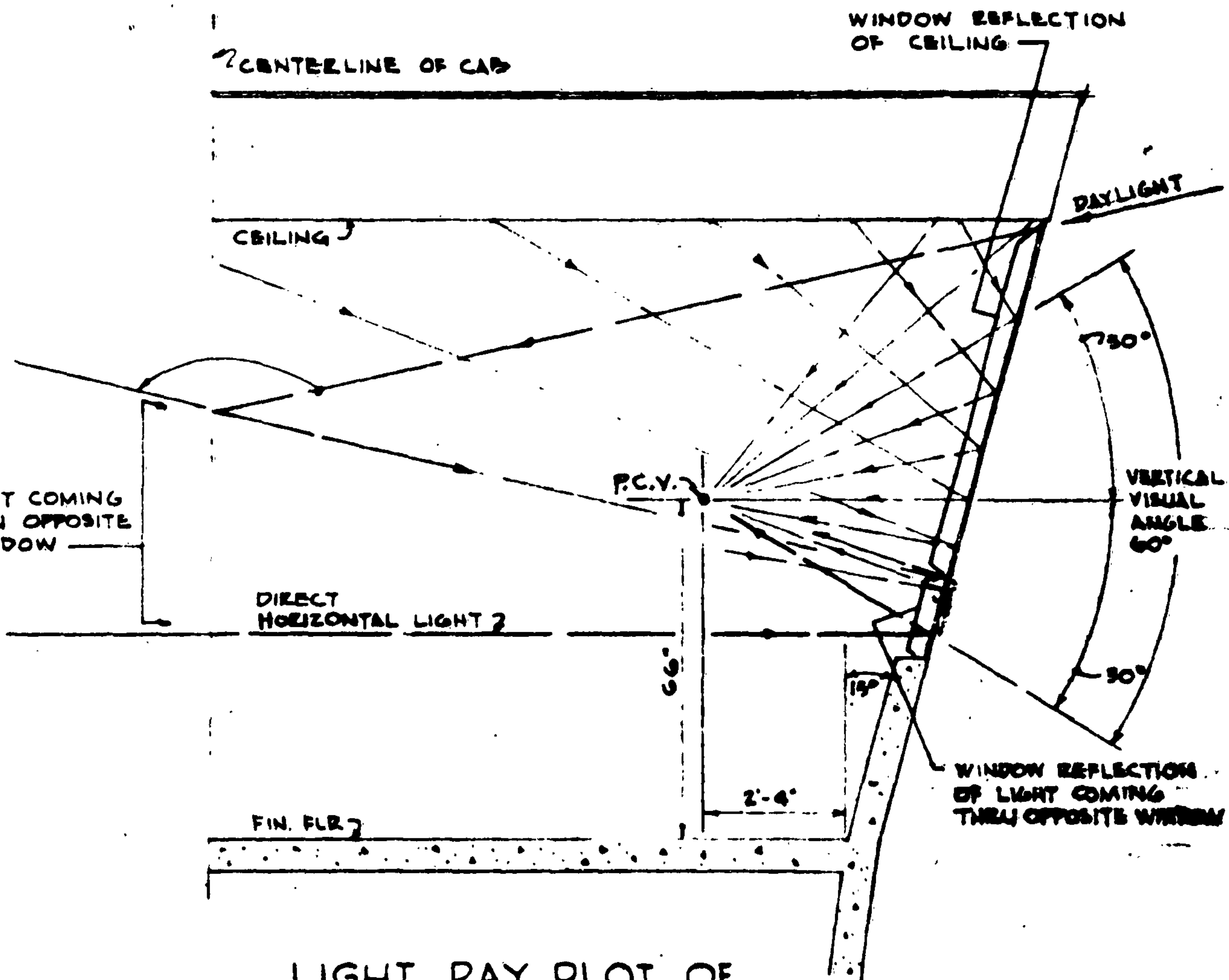
FIGURE 1



LIGHT RAY PLOT OF WINDOW SLANTED 12.5°

SCALE 3/8" = 1'-0"

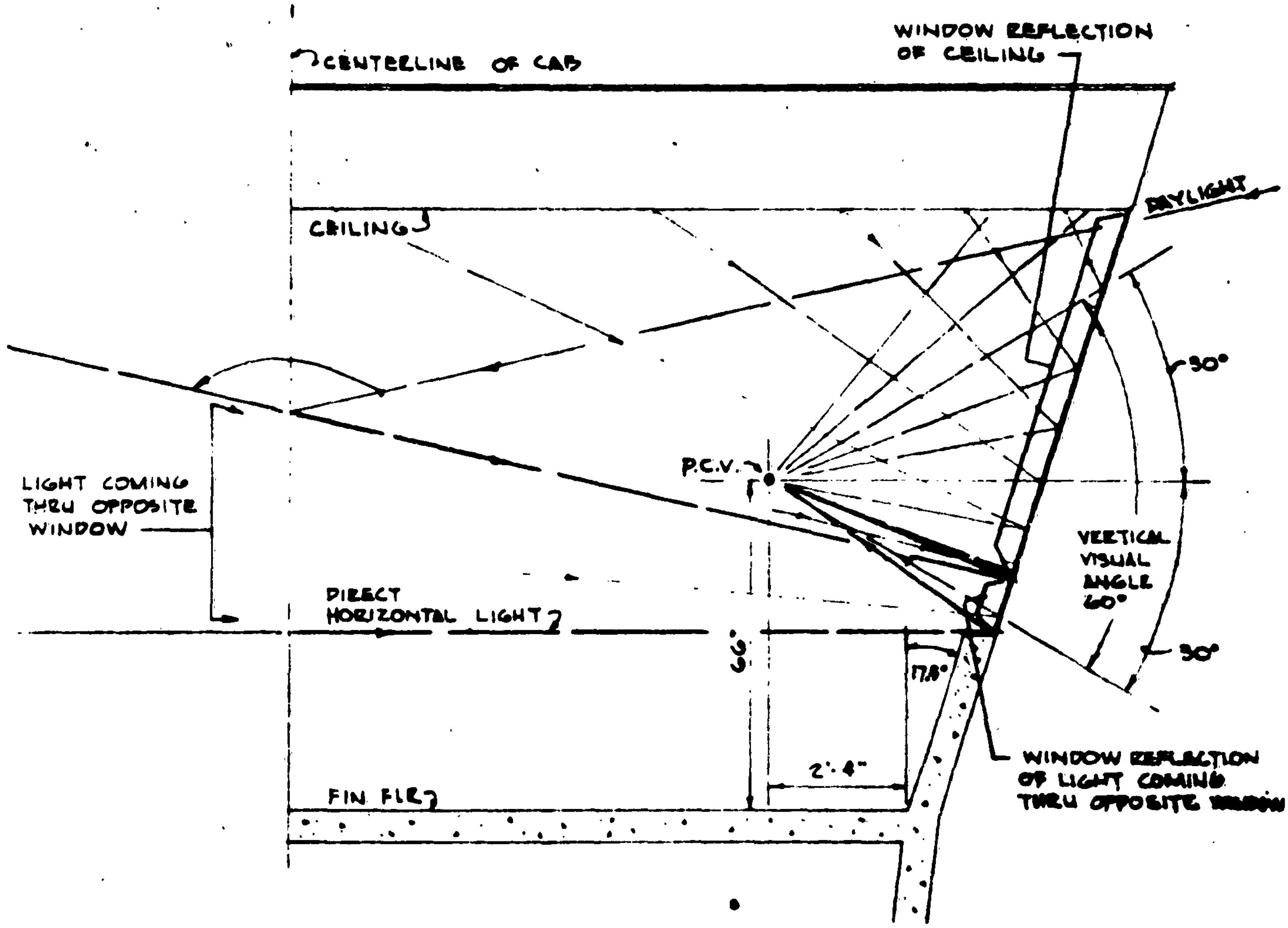
FIGURE 2



LIGHT RAY PLOT OF WINDOW SLANTED 15°

SCALE: 3/8" = 1'-0"

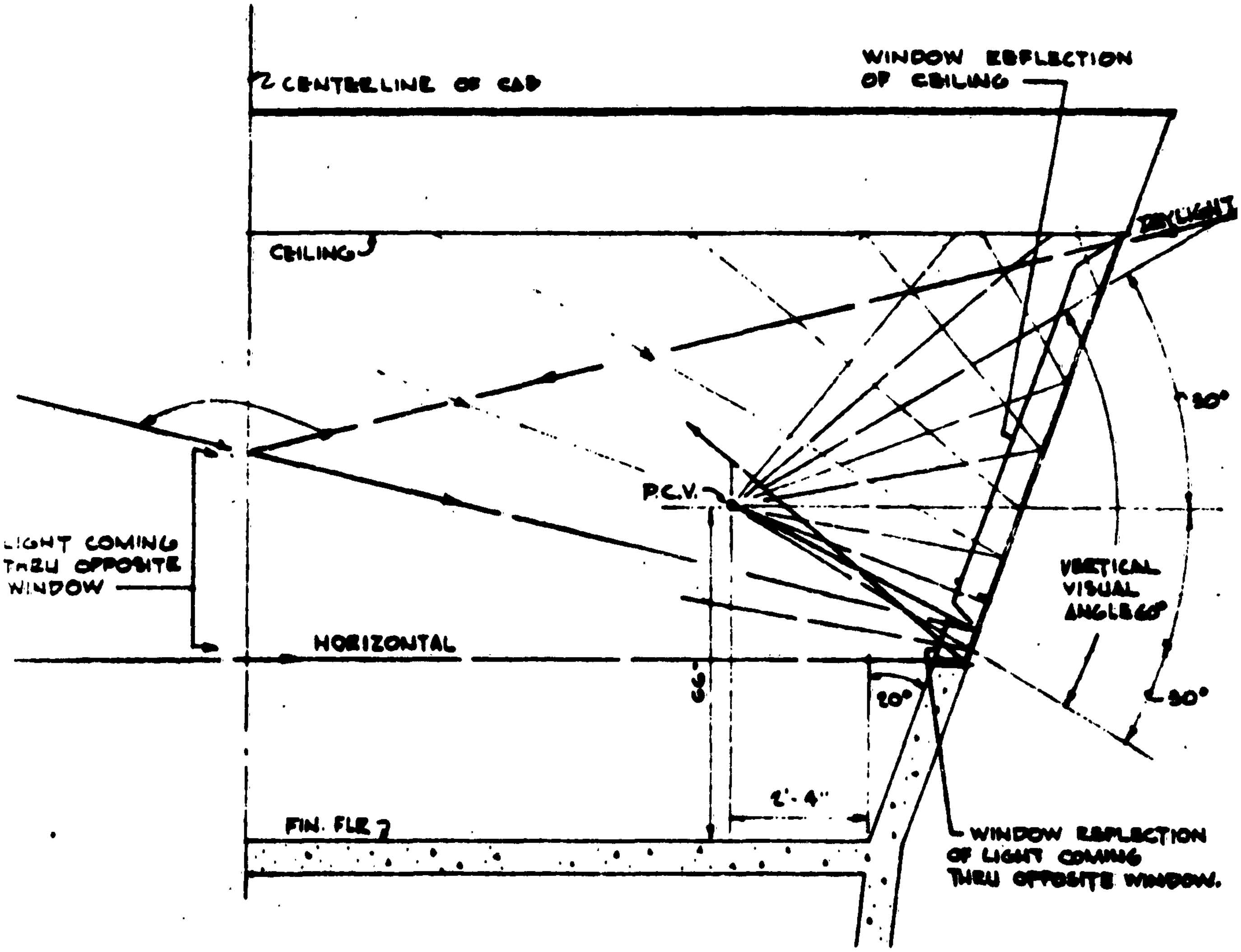
FIGURE 8



LIGHT RAY PLOT OF WINDOW SLANTED 17.5°

SCALE: 3/8" = 1'-0"

FIGURE 6



LIGHT RAY PLOT OF WINDOW SLANTED 20°

SCALE: 3/8" = 1'-0"

FIGURE 5

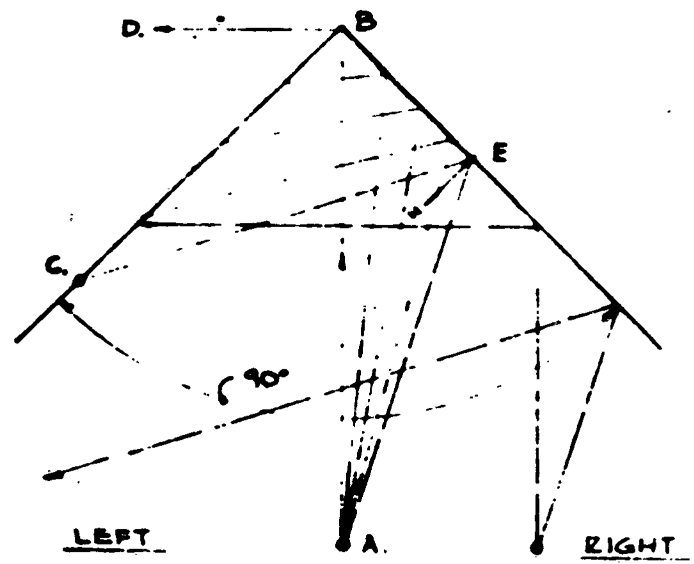


FIGURE 11.
CORNER OF FOUR SIDED CAB.

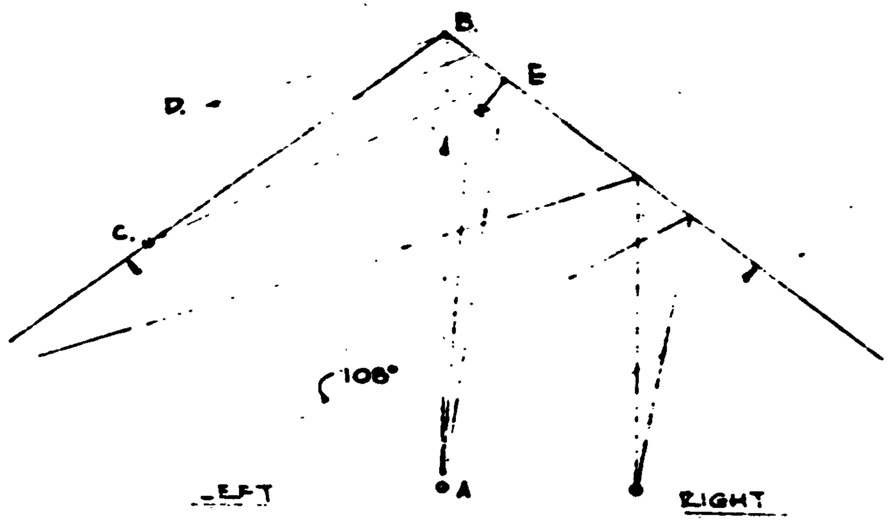


FIGURE 12.
CORNER OF FIVE SIDED CAB.

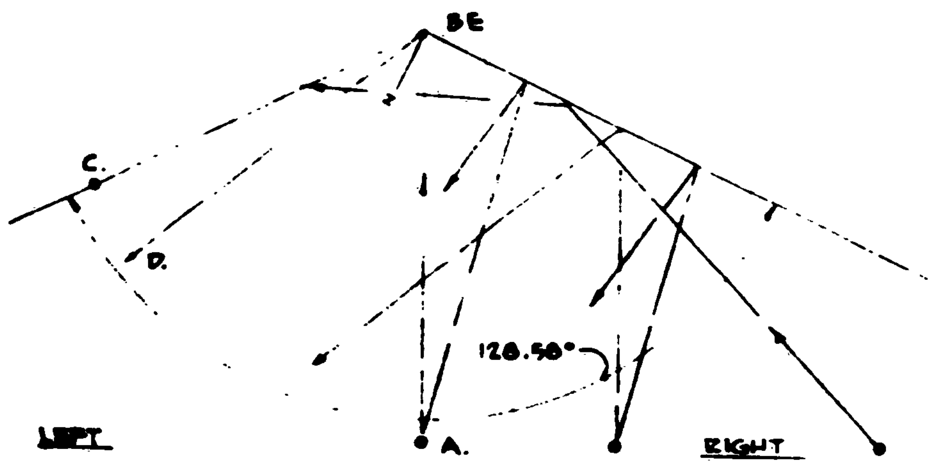


FIGURE 13.
CORNER OF SEVEN SIDED CAB.

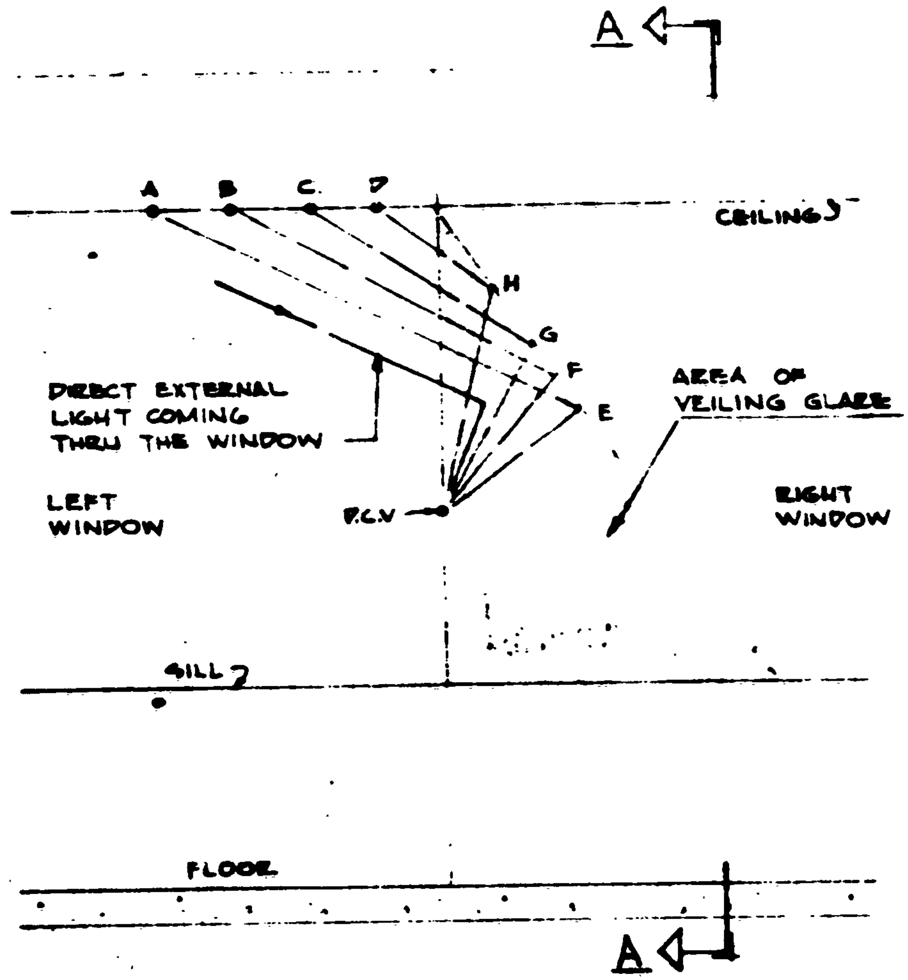


FIGURE 14 INSIDE ELEVATION

90° CORNER

SCALE: 3/8" = 1'-0"

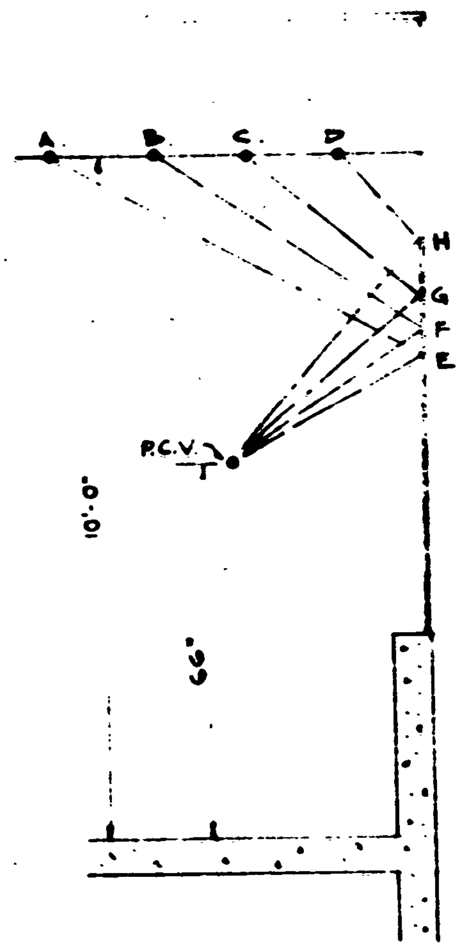


FIGURE 15 SECTION 'A-A'

SCALE: 3/8" = 1'-0"

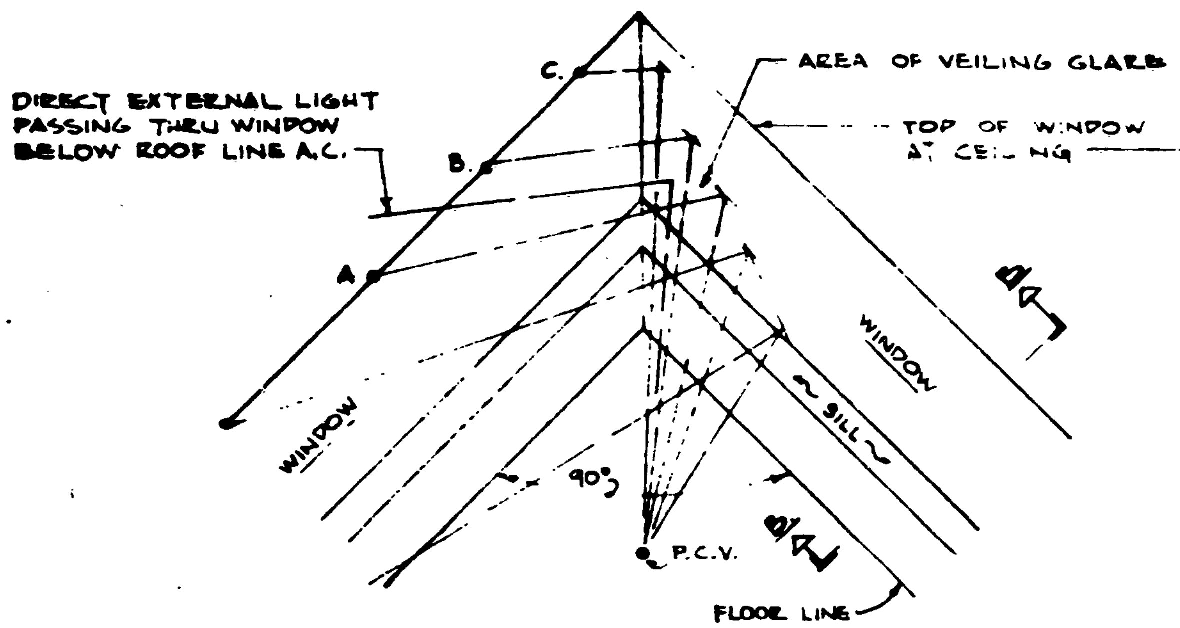


FIGURE 16 PLAN VIEW - 90° CORNER

15° WINDOW SLANT

SCALE: 3/8" = 1'-0"

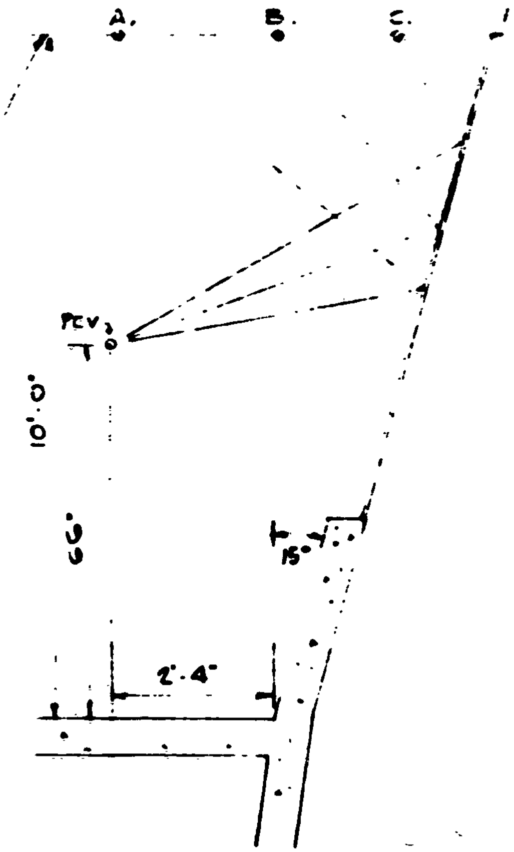


FIGURE 17 SECTION 'B-B'

SCALE: 3/8" = 1'-0"

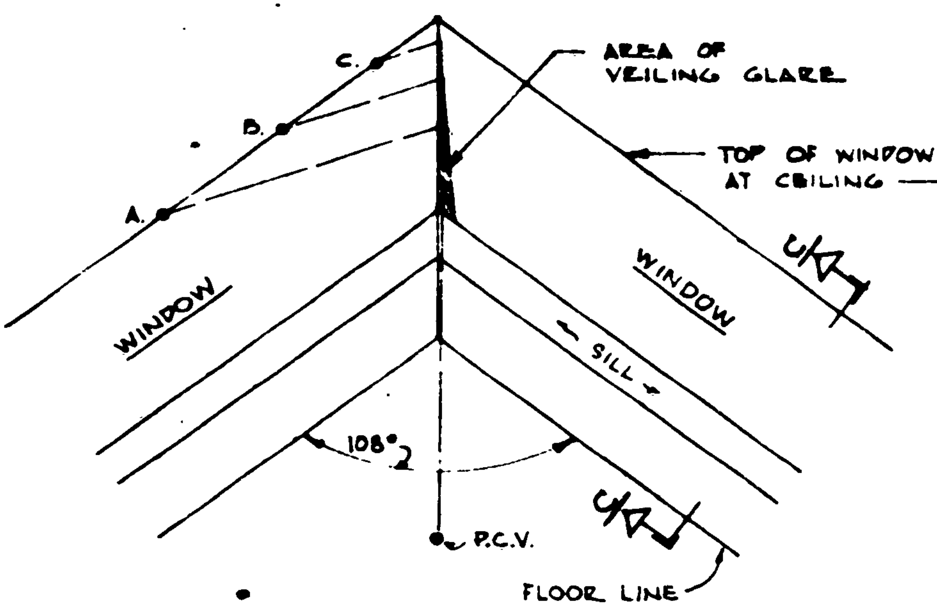


FIGURE 18 PLAN VIEW - 108° CORNER
17.5° WINDOW SLANT

SCALE: 3/8" = 1'-0"

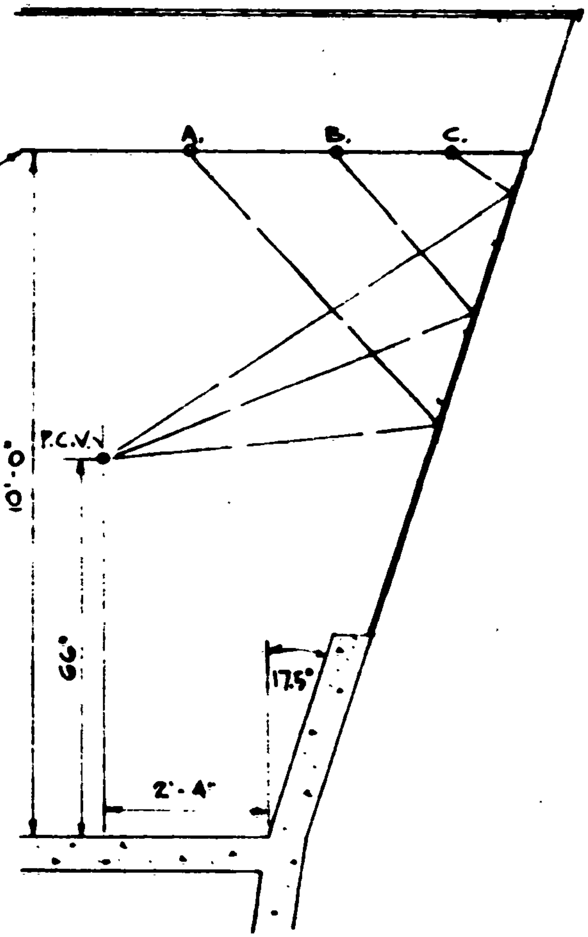
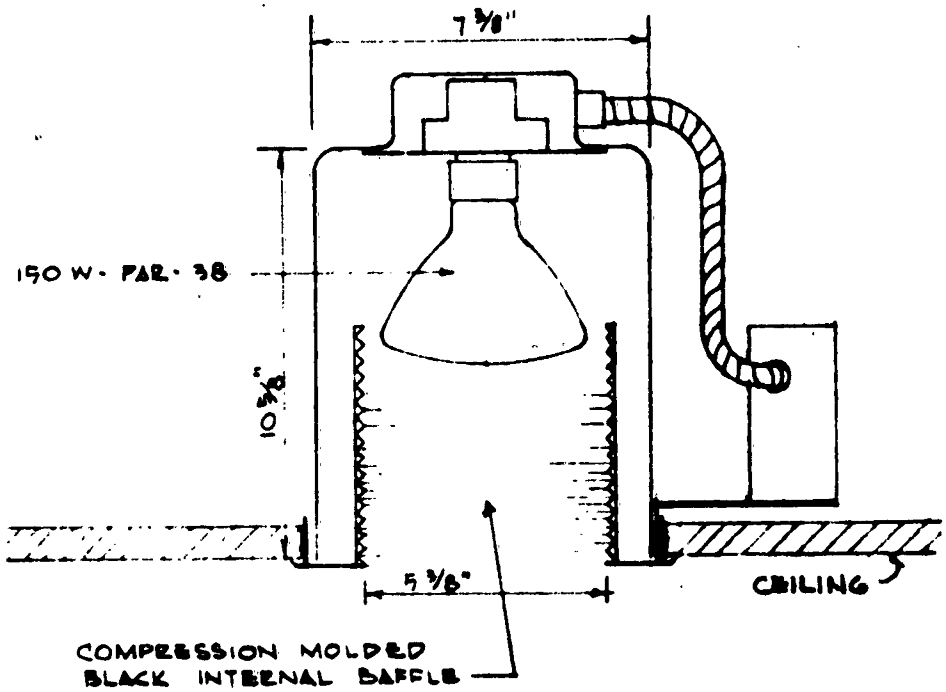


FIGURE 19 SECTION 'C-C'

SCALE: 3/8" = 1'-0"



RECESSED INCANDESCENT

LIGHTING FIXTURE

TOWER CAB LIGHTING

SCALE : N.T.S.

APPENDIX D

QUESTIONNAIRE GIVEN TO CONTROLLER SUBJECTS

PROJECT LOOKING GLASS

Controller Opinion Survey

Date ______________ Time of Day (0000-2400) ______________ Type of Control "Assignment" Local ☑ Ground ☐

PART I
Controller Experience Data

How long have you been an ATC specialist? _______ Years. Center ______ Years. Tower ______ Years. Local Control ______ Years. Ground Control ______ Years. Both (rotating) ______ Years.

Please describe your activities during the past five years of your control experience more closely by checking the boxes below. Do not split years; use the greater portion of the year. If you were in another field than air traffic control write "N A.".

	Tower Activity Class				Tower Shape				Assignment				
Year	I	II	III	IV	Square (like Pittsburgh)	Modified Eight Sided (like Idlewild)	Eight equal Sides (like NAFEC)	Other	Ground Control	Local Control	Both (Rotating)	Other Tower Positions	Center
1962													
1961													
1960													
1959													
1958													

Do you normally wear sunglasses while in the tower cab? Yes___ No ___ **If you do wear sunglasses, do you wear them** all the time___? part of the time___?

If you wear sunglasses only part of the time, is there any particular time of the day when you wear them? Sunrise___ Sunset___ Midafternoon___ Other____

Part TWO - A Rating of the IMPORTANCE of certain DESIGN FEATURES

Certain features of tower design will be listed below. We want you to indicate the importance of each item by using the rating scale provided. Additional space will be provided for you to add items in either the visual features or workspace layout which could influence job performance positively or adversely.

Please keep in mind that you are rating the importance of features generally found in most tower designs. We want you to estimate the possible IMPACT of these features on job performance. The presence or absence of certain things, or possibly just the manner in which they are arranged, can improve or reduce job performance. Other things may not make any difference to your performance. The purpose here is to guide the design effort to concentrate on those features that controllers feel MATTER.

Rate the following design features for impact on tower control performance; be sure to check one of the four answers for each item.

	NO IMPACT ON ON JOB PERFORMANCE	MODERATE IMPACT ON JOB PERFORMANCE	STRONG IMPACT ON JOB PERFORMANCE	CAN'T SAY
1. Presence or absence of tinted glass.	___	___	___	___
2. Large interrupted areas of glass.	___	___	___	___
3. Tilt or outward slope of glass.	___	___	___	___
4. Amount of floor space in tower cab.	___	___	___	___
5. Number of sides the tower cab has.	___	___	___	___
6. All interior paint work of dark, non-reflecting colors.	___	___	___	___
7. Presence or absence of outside catwalk.	___	___	___	___
8. Presence or absence of permanent railing on outside catwalk.	___	___	___	___
9. Location of stair well with respect to the working area.	___	___	___	___
10. Overall console design.	___	___	___	___

(Continued)
Rate the following design features for impact on tower control performance; be sure to check one of the four answers for each item.

	NO IMPACT ON ON JOB PERFORMANCE	MODERATE IMPACT ON JOB PERFORMANCE	STRONG IMPACT ON JOB PERFORMANCE	CAN'T SAY
11. Height of writing surface on console.	___	___	___	___
12. Location of your assigned controller's position with respect to other controller positions.	___	___	___	___
13. Location of your assigned controller's position with respect to ASDE.	___	___	___	___
14. Location of your assigned controller's position with respect to ASR.	___	___	___	___
15. Height of tower cab above ground.	___	___	___	___
16. Nearness of tower cab to runways.	___	___	___	___
17. Ability to see both ends of active runway.	___	___	___	___
18. Ability to see runway turn-offs.	___	___	___	___
19. Ability to see taxiways.	___	___	___	___
20. Ability to see run up areas.	___	___	___	___

(Continued)

Rate the following design features for impact on tower control performance; be sure to check one of the four answers for each item.

	NO IMPACT ON ON JOB PERFORMANCE	MODERATE IMPACT ON JOB PERFORMANCE	STRONG IMPACT ON JOB PERFORMANCE	CAN'T SAY
21. Ability to see ramp areas.	___	___	___	___
22. Ability to see aircraft on final approach.	___	___	___	___
23. Reflections on glass only in the corners.	___	___	___	___
24. Reflections on glass in locations other than at the corners.	___	___	___	___
25. Location of visual obstructions.	___	___	___	___
26. Number of visual obstructions.	___	___	___	___
Add other features you feel have an effect on job performance.				
27.	___	___	___	___
28.	___	___	___	___
29.	___	___	___	___
30.	___	___	___	___

PART III
A Comparative Rating of Tower Cab Features

Now that you have rated certain features for importance, we want you to make a comparison of the features of this cab with the features found in the tower cab with which you are most experienced. We want you to consider how each factor would affect your performance when handling aircraft traffic.

Before rating, fix in your mind the tower cab you will use as a base of comparison.

Describe that tower cab:

Class I	Square Cab (like Pittsburgh Tower)________________
Class II	Modified 8 Sided (like Idlewild Tower)________________
Class III	8 Equal Sides (like NAFEC Tower)________________
Class IV	Other____________________________

Rate the following design features by comparing this cab with the one with which you have the most experience:

	BOTH CABS ABOUT THE SAME	THE ARRANGEMENT HERE IS MUCH WORSE THAN IN MY OLD TOWER	THE ARRANGEMENT HERE IS CONSIDERABLY MORE HELPFUL THAN IN MY OLD TOWER	CAN'T SAY
1. Presence or absence of tinted glass.	___	___	___	___
2. Large interrupted areas of glass.	___	___	___	___
3. Tilt or outward slope of glass.	___	___	___	___
4. Amount of floor space in tower cab.	___	___	___	___
5. Number of ~~slides~~ sides the tower cab has.	___	___	___	___
6. All interior paint work of dark, non-reflecting colors.	___	___	___	___
7. Presence or absence of outside catwalk.	___	___	___	___
8. Presence or absence of permanent railing on outside catwalk.	___	___	___	___
9. Location of stair well, with respect to the working area.	___	___	___	___
10. Overall console design.	___	___	___	___
11. Height of writing surface on console.	___	___	___	___

(Continued)

Rate the following design features by comparing this cab with the one with which you have the most experience:

	BOTH CABS ABOUT THE SAME	THE ARRANGEMENT HERE IS MUCH WORSE THAN IN MY OLD TOWER	THE ARRANGEMENT HERE IS CONSIDERABLY MORE HELPFUL THAN IN MY OLD TOWER	CAN'T SAY
12. Location of your assigned controller's position with respect to other controller positions.	___	___	___	___
13. Location of your assigned controller's position with respect to ASDE.	___	___	___	___
14. Location of your assigned controller's position with respect to ASR.	___	___	___	___
15. Height of tower cab above ground.	___	___	___	___
16. Nearness of tower cab to runways.	___	___	___	___
17. Ability to see both ends of active runway.	___	___	___	___
18. Ability to see runway turn-offs.	___	___	___	___
19. Ability to see taxiways.	___	___	___	___
20. Ability to see run up areas.	___	___	___	___
21. Ability to see ramp areas.	___	___	___	___

(Continued)

Rate the following design features by comparing this cab with the one with which you have the most experience:

	BOTH CABS ABOUT THE SAME	THE ARRANGEMENT HERE IS MUCH WORSE THAN IN MY OLD TOWER	THE ARRANGEMENT HERE IS CONSIDERABLY MORE HELPFUL THAN IN MY OLD TOWER	CAN'T SAY
22. Ability to see aircraft on final approach.	___	___	___	___
23. Reflections on glass only in the corners.	___	___	___	___
24. Reflections on glass in locations other than at the corners.	___	___	___	___
25. Location of visual obstructions.	___	___	___	___
26. Number of visual obstructions.	___	___	___	___

Add those features you added on the previous page, andrate them.

27.	___	___	___	___
28.	___	___	___	___
29.	___	___	___	___
30.	___	___	___	___

PART IV

Tower - Airport Configuration Sketches

This part of the questionnaire contains sixteen sketches of one particular portion of an airport. These sketches are not scaled drawings because of the necessity to clearly show the tower cab. Each sketch contains four principle items. They are:

1. A shaded area denoting administration or other airport buildings.

2. The outline of a tower cab.

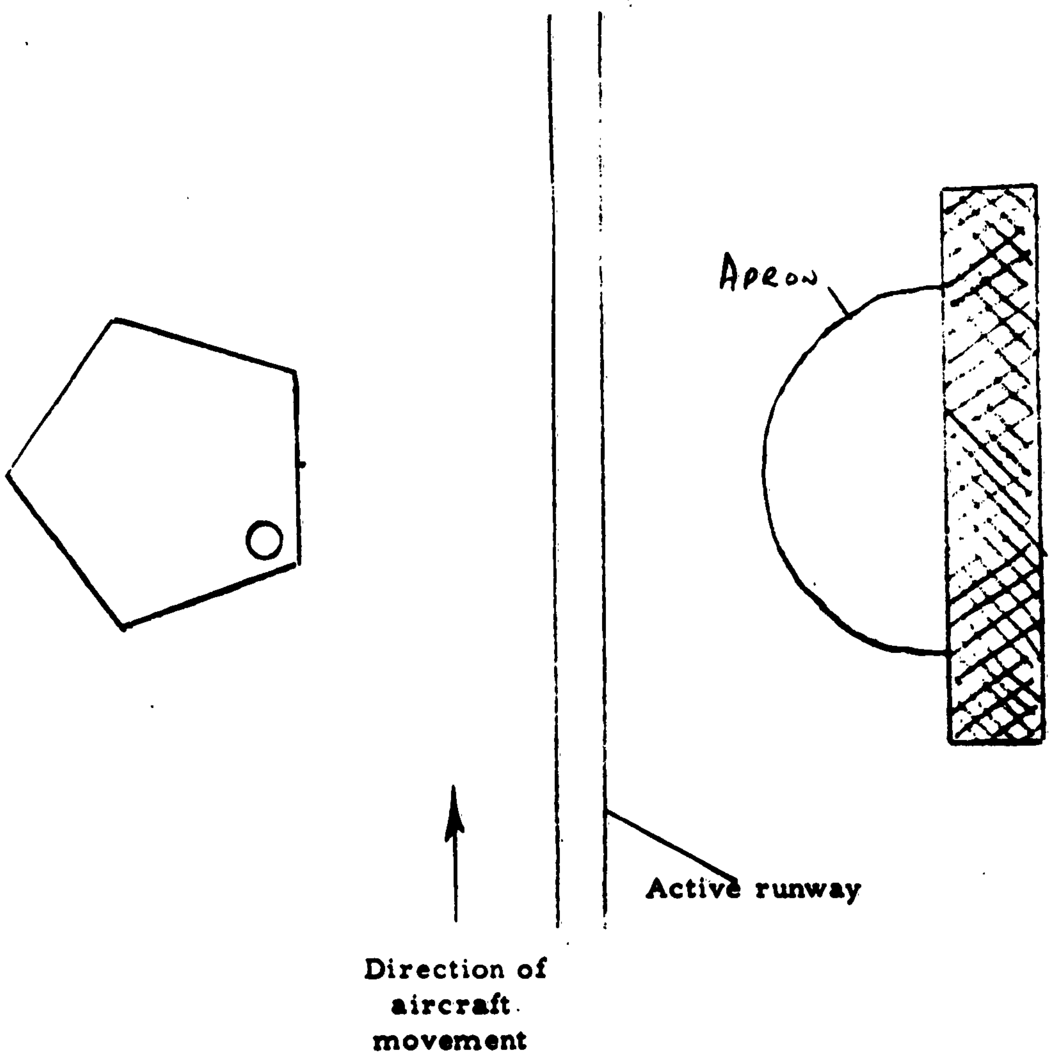
3. A portion of the approach end of the active runway.

4. A circle to indicate the position of that type controller position that has been assigned to you (either local or ground control).

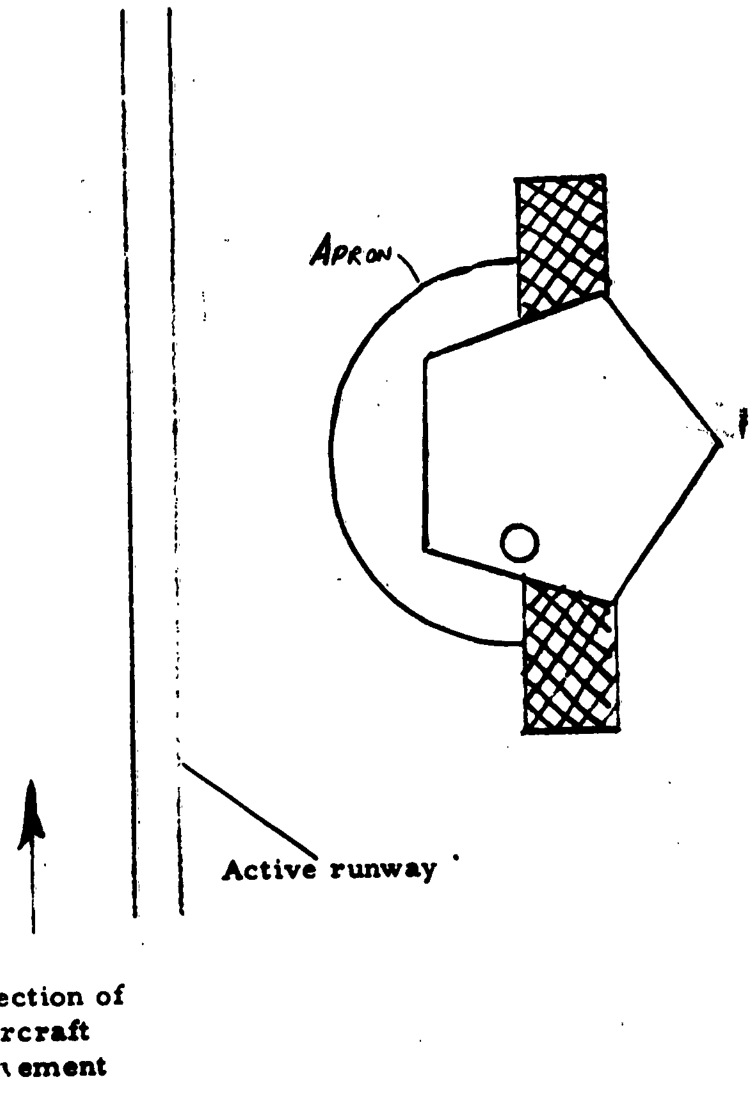
The information we desire is independent of such things as the direction of the sun, time of day or the location of other crossing runways.

Consider the entire configuration of each sketch. Note especially the visual requirements of the controller's position as depicted in each sketch. You might prefer a slightly different control position from that shown, however for the purposes of this questionnaire we ask that you confine your considerations to <u>only</u> the depicted alternatives.

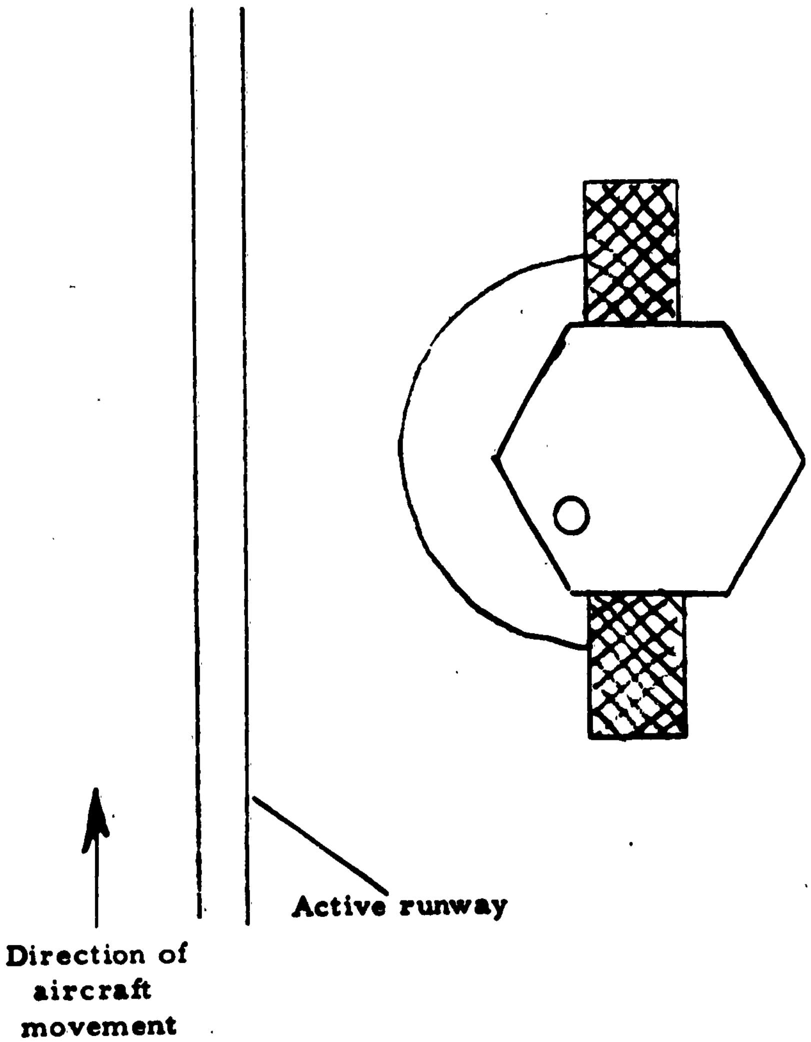
Rate each sketch for its desirability to you as a working controller.



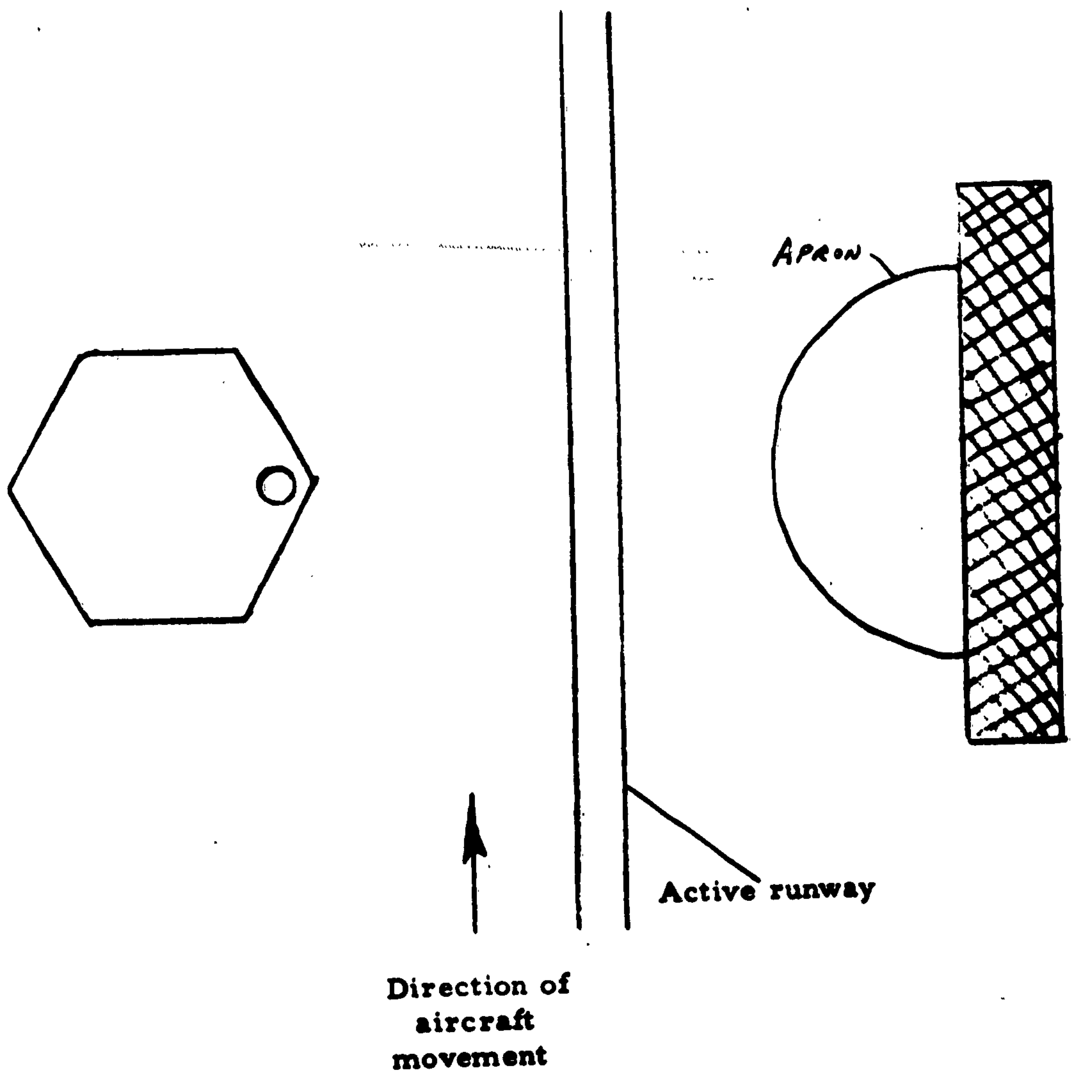
☐ Very poor ☐ Poor ☐ Average ☐ Good ☐ Very good



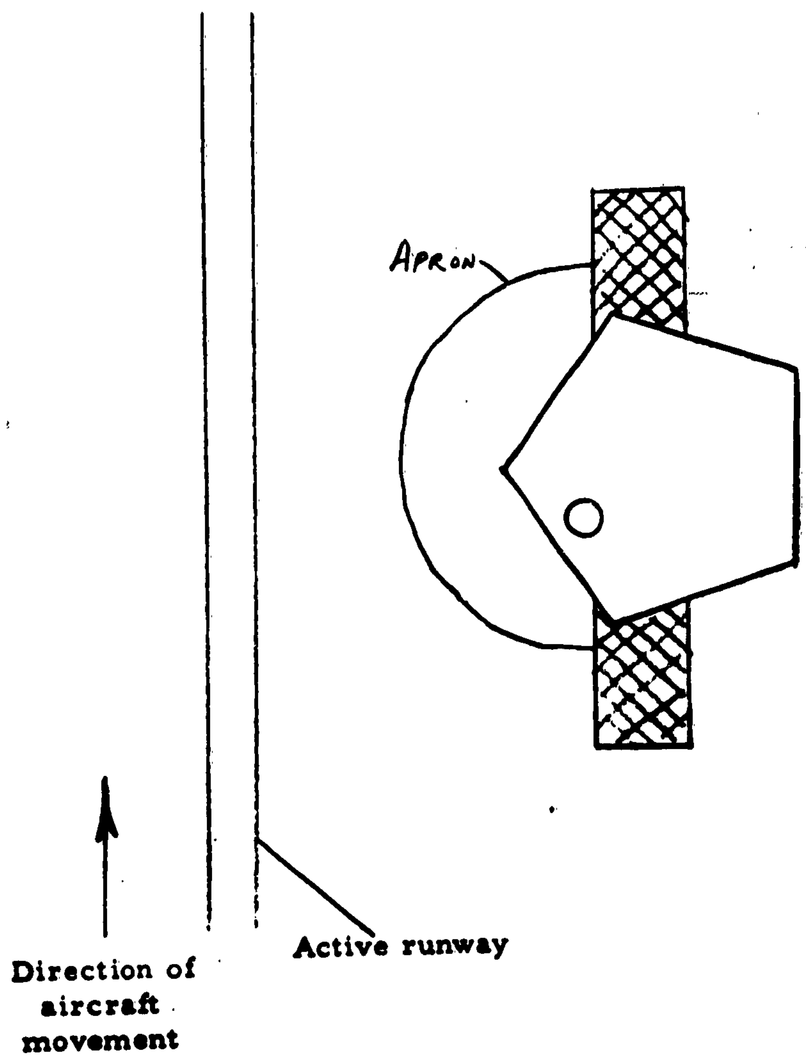
☐ Very poor ☐ poor ☐ Average ☐ Good ☐ Very good



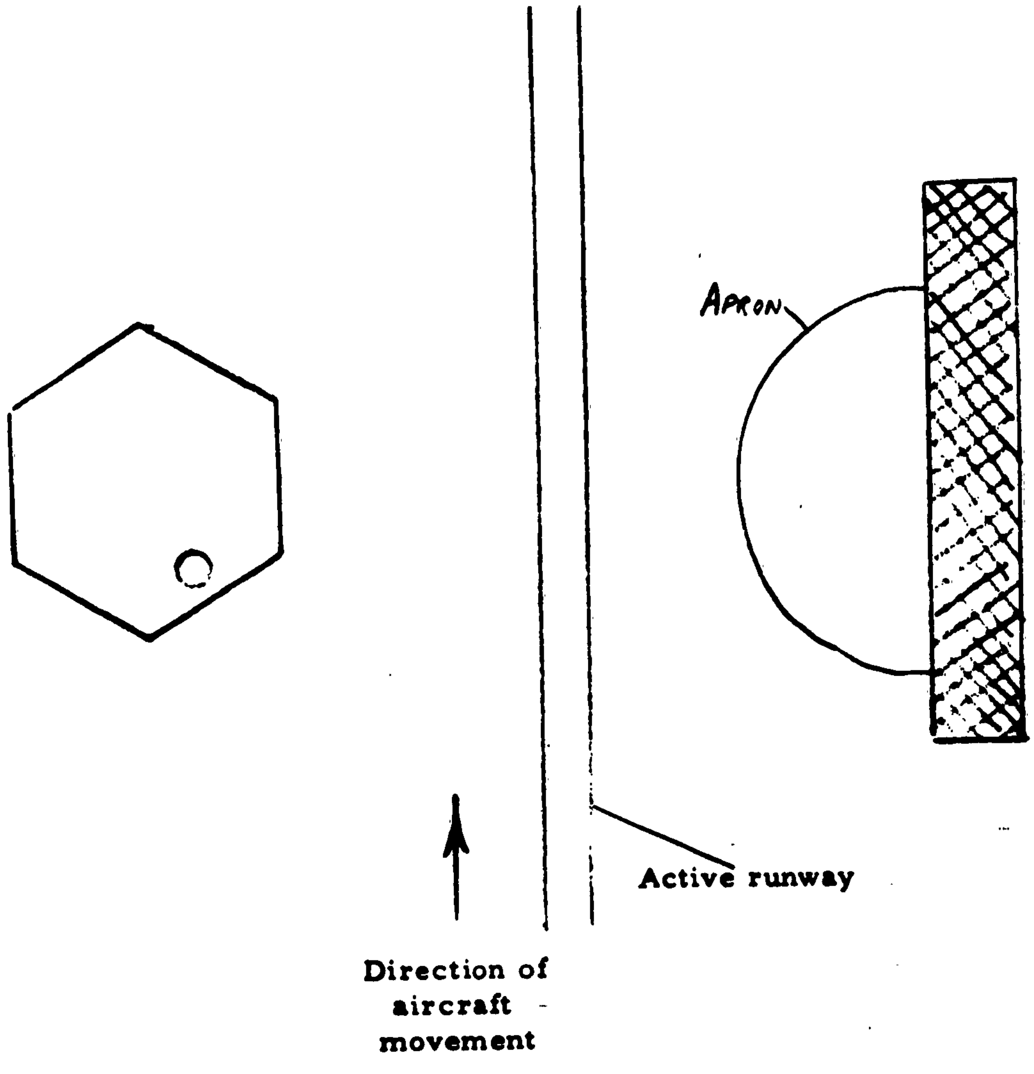
☐ Very poor ☐ Poor ☐ Average ☐ Good ☐ Very good



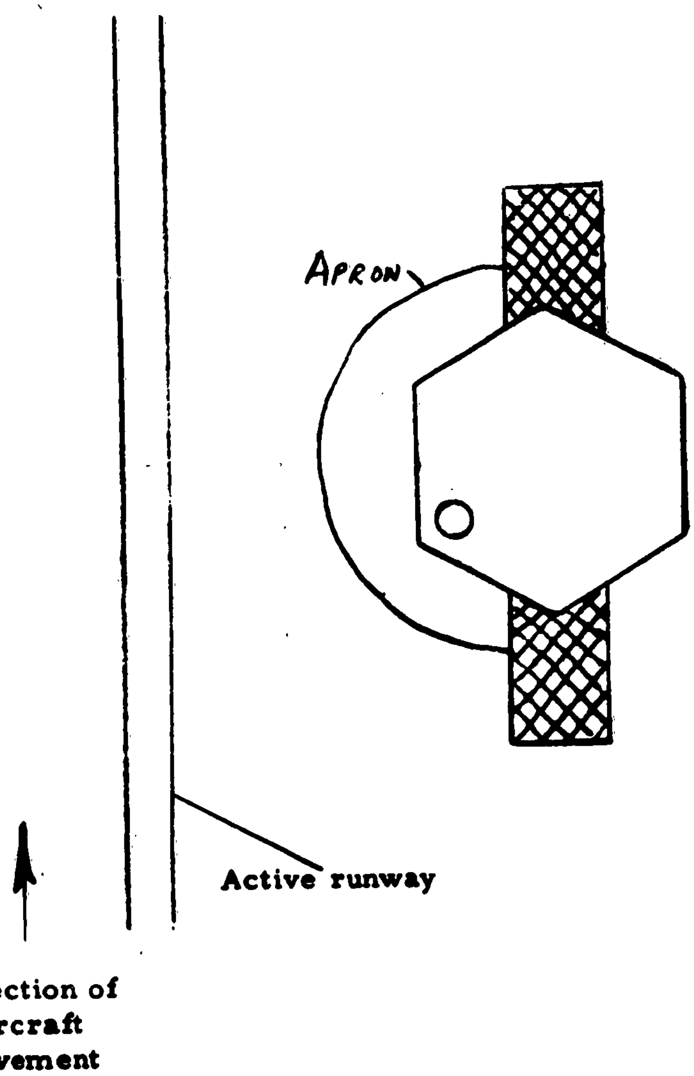
☐ Very poor ☐ Poor ☐ Average ☐ Good ☐ Very good



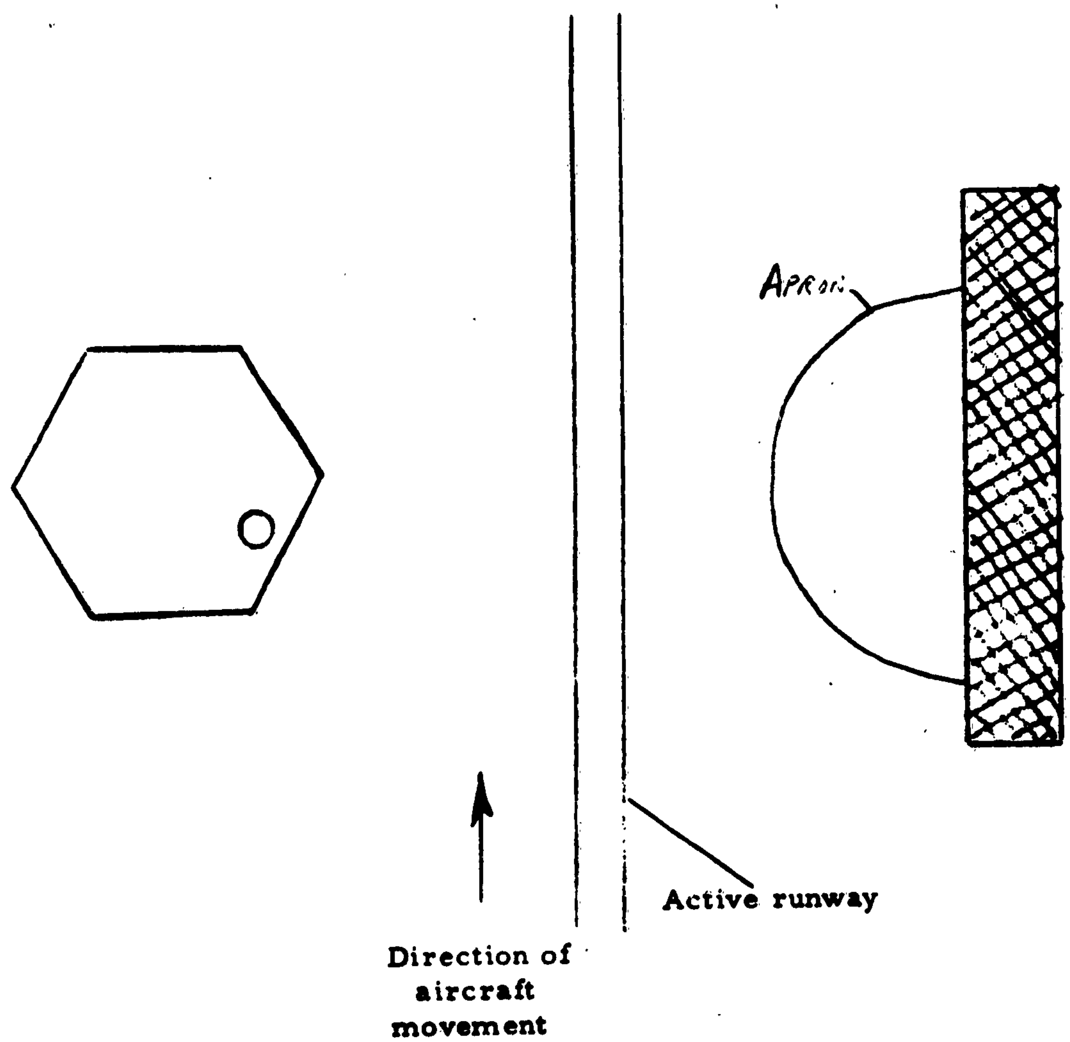
☐ Very poor ☐ Poor ☐ Average ☐ Good ☐ Very good



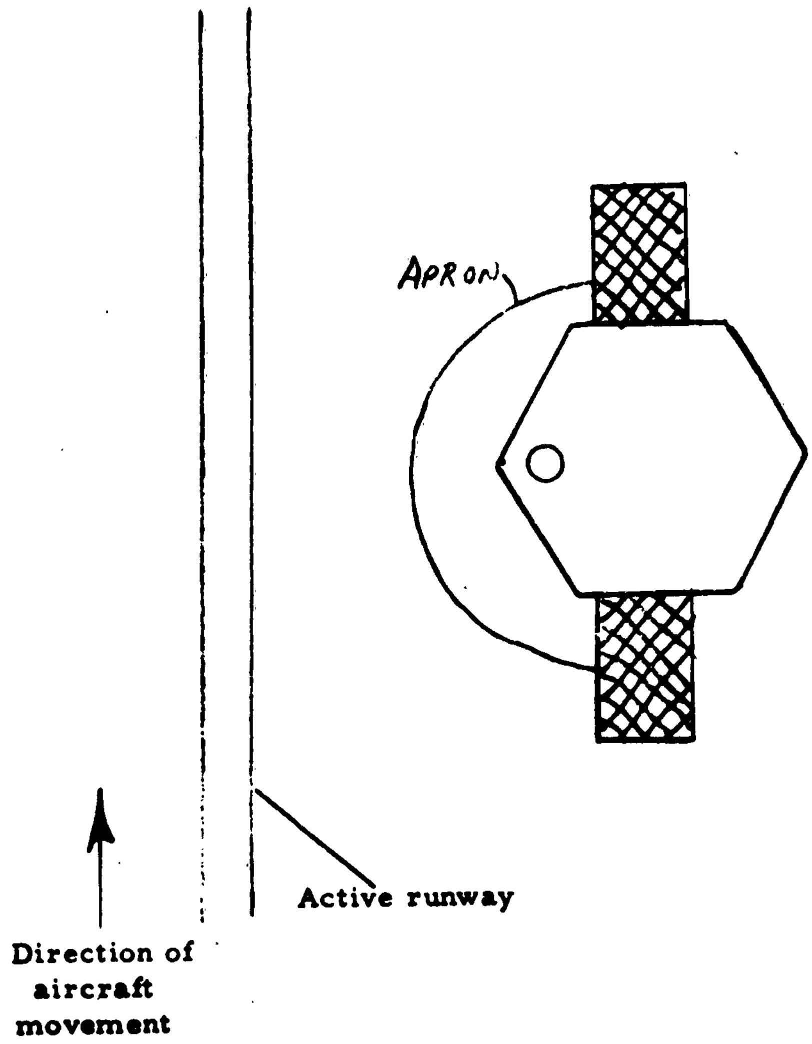
☐ Very poor ☐ Poor ☐ Average ☐ Good ☐ Very good



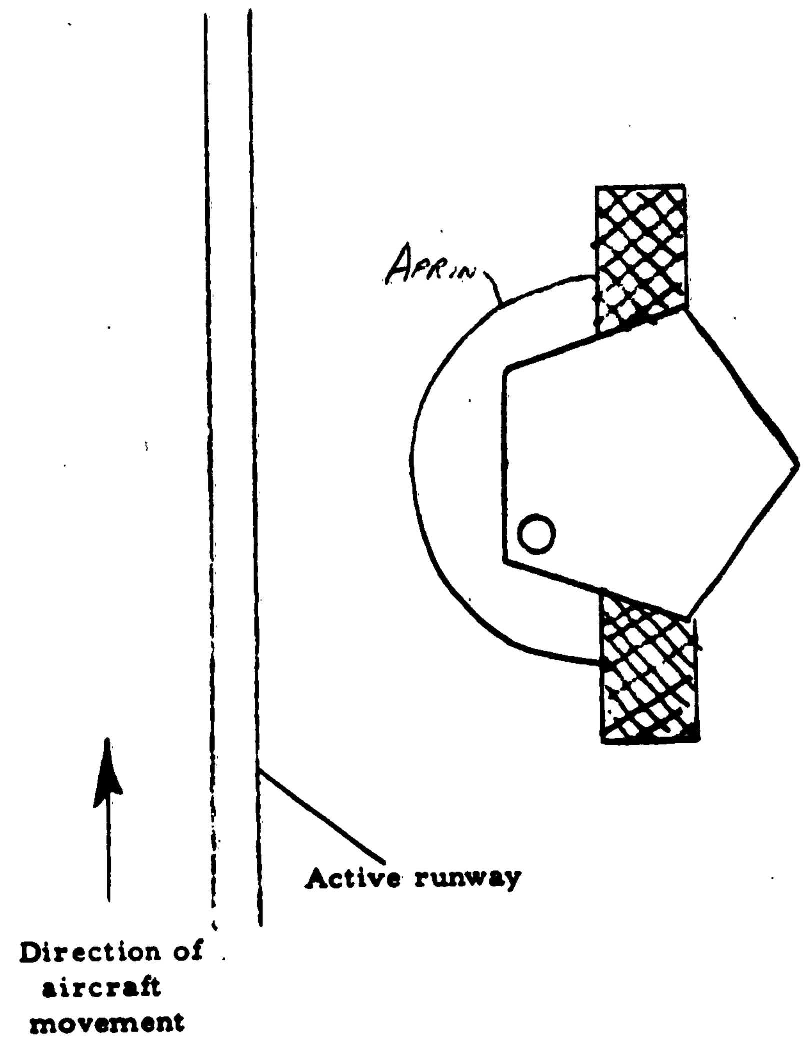
☐ Very poor ☐ Poor ☐ Average ☐ Good ☐ Very good



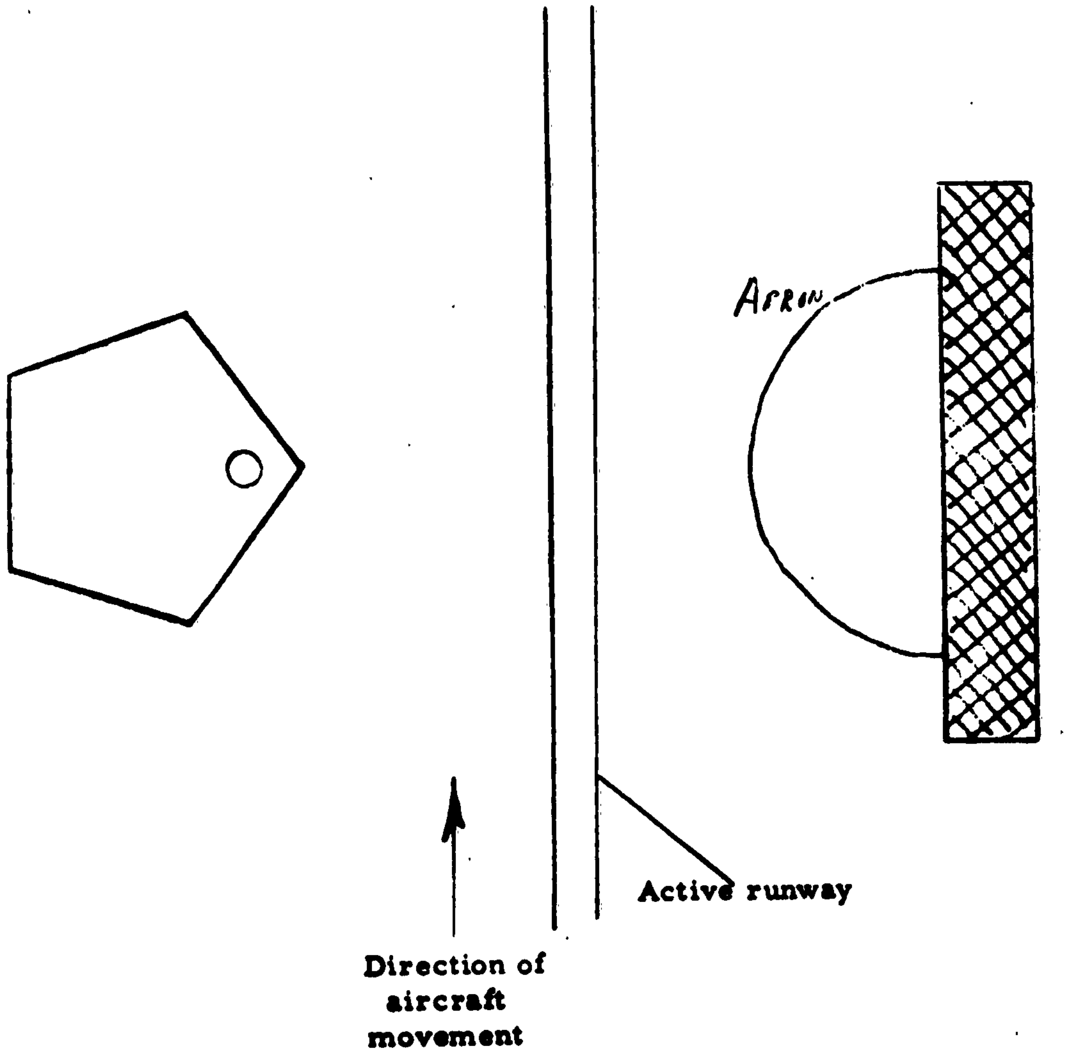
☐ Very poor ☐ Poor ☐ Average ☐ Good ☐ Very good



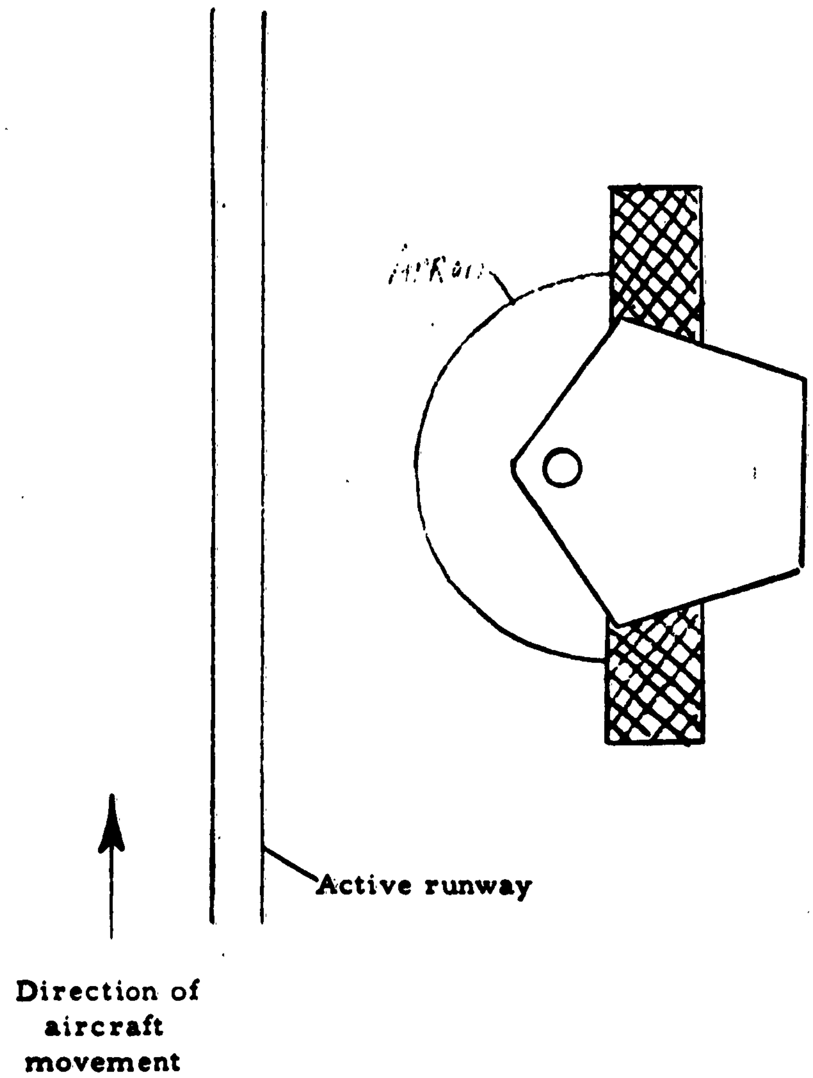
☐ Very poor ☐ Poor ☐ Average ☐ Good ☐ Very good



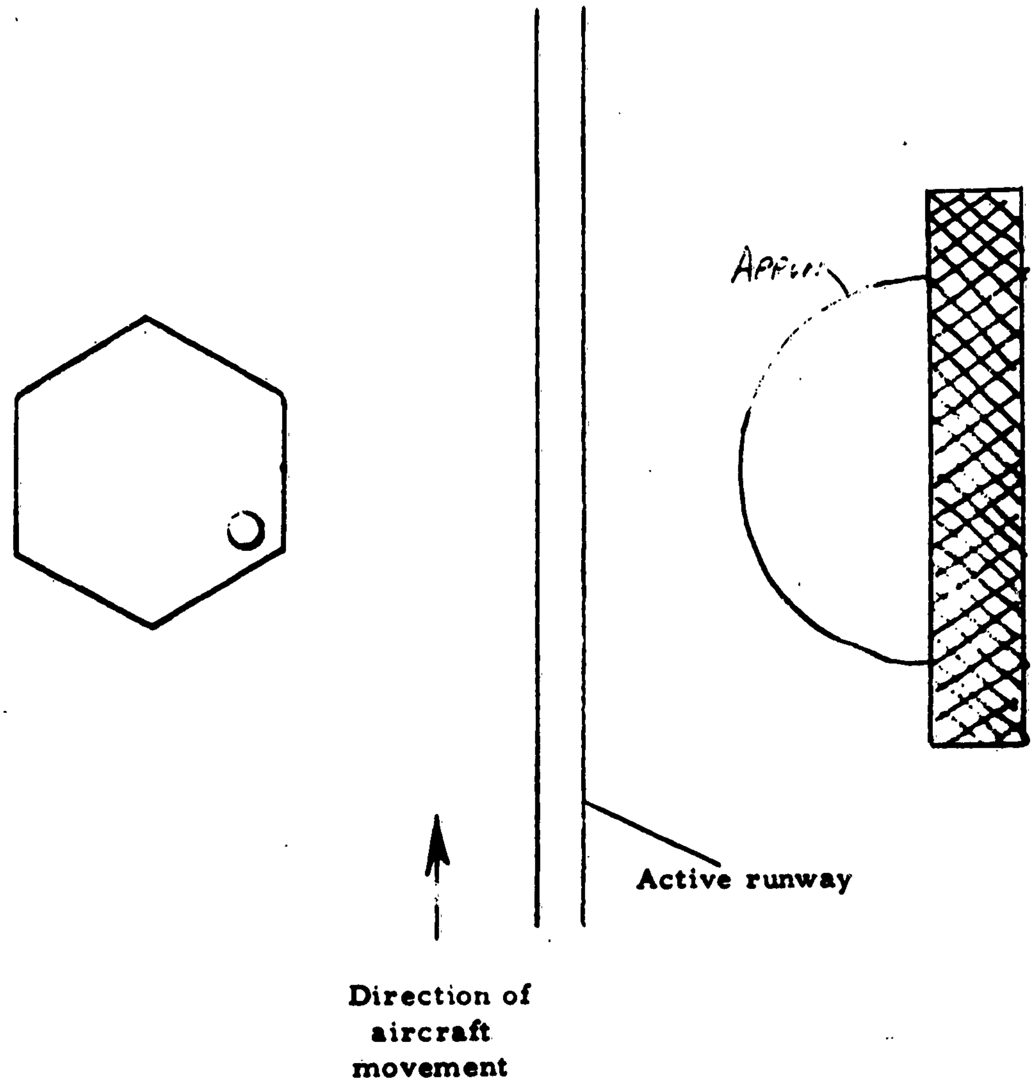
☐ Very poor ☐ Poor ☐ Average ☐ Good ☐ Very good



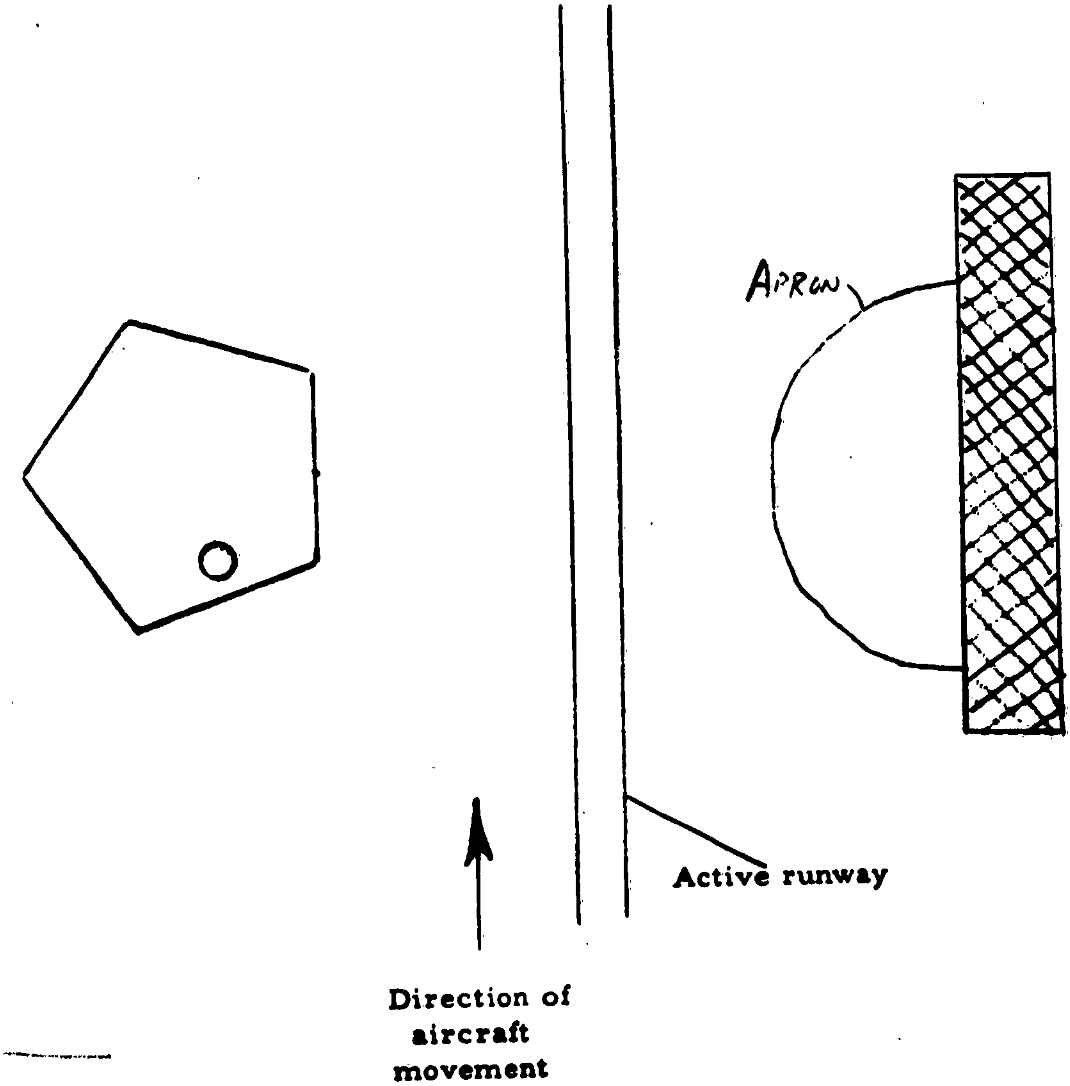
☐ Very poor ☐ Poor ☐ Average ☐ Good ☐ Very good



☐ Very poor ☐ Poor ☐ Average ☐ Good ☐ Very good



☐ Very poor ☐ Poor ☐ Average ☐ Good ☐ Very good



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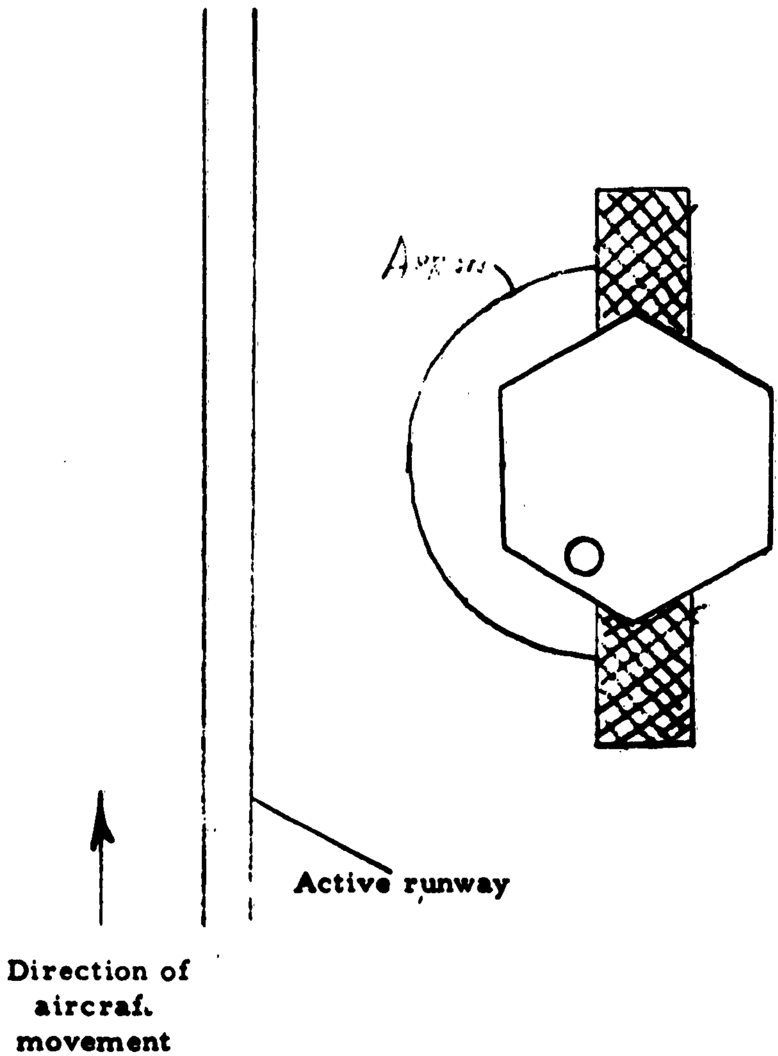

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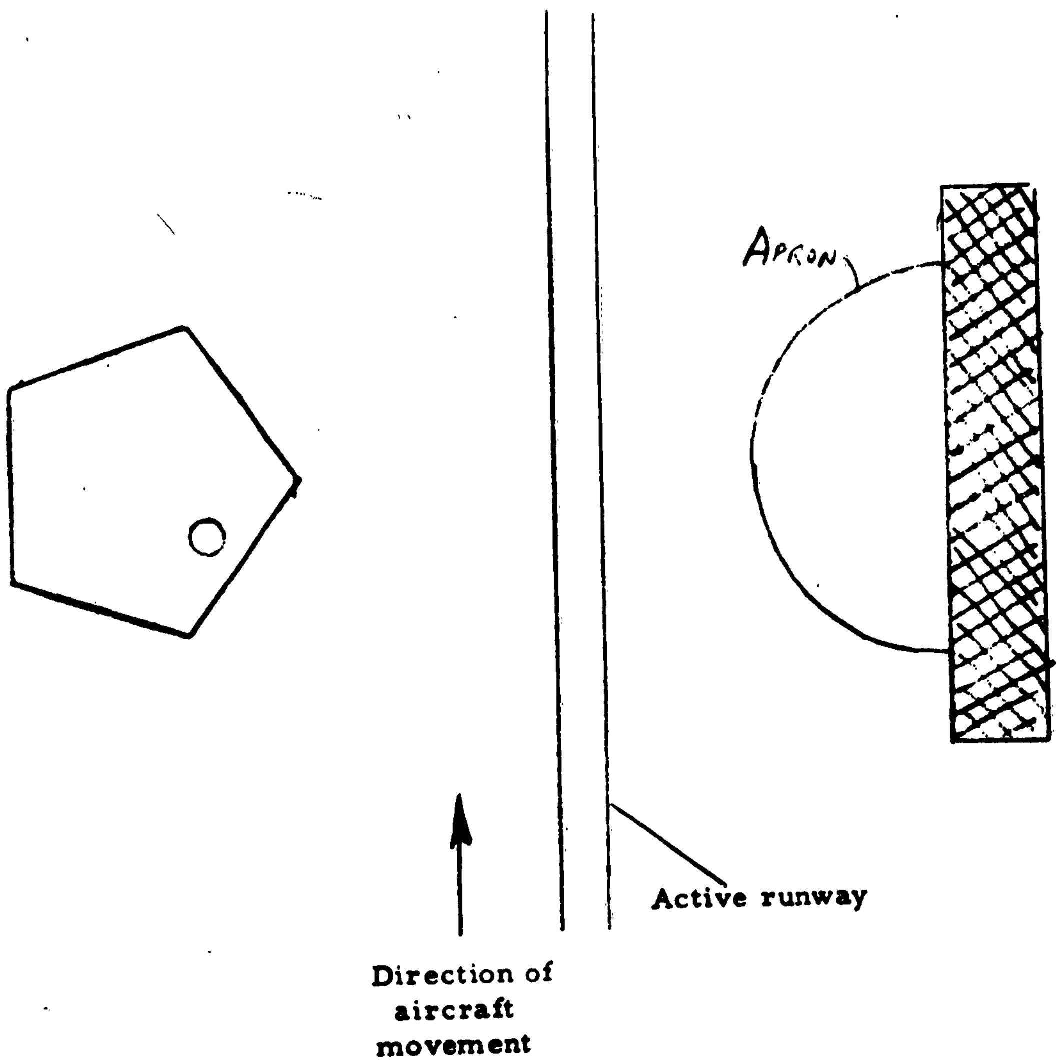

☐ Very poor ☐ Poor ☐ Average ☐ Good ☐ Very good

PART V

Questions of Special Interest

This Part contains seven specific questions of particular interest to the designers of this cab. We will demonstrate, with mockups, some of the alternative arrangements that are still being considered and ask you to express your preferences.

	POSSIBLY MUCH BETTER	NO DIFFERENCE	POSSIBLY MUCH WORSE	CAN'T SAY
1. Consider the glass support erected at one window joint. If the other four glass joints had equal supports how would your performance be affected?	___	___	___	___
2. If the five roof supports were removed and replaced by one support located at the rear of the cab, how do you feel your performance would be affected?	___	___	___	___
3. If the five roof supports were removed and replaced by one <u>central</u> support, how do you feel your performance would be affected?	___	___	___	___

(Continued)

	POSSIBLY MUCH BETTER	NO DIFFERENCE	POSSIBLY MUCH WORSE	CAN'T SAY
4. To see all the runway including the ends would you want a low tower close to the runway rather than a high tower farther back? (For Example airport regulations prescribe a 50' high tower cab to be 850' from the centerline of an ILS runway. An 80' high tower cab would be 1060' away).	___	___	___	___
5. If this tower were located near airport or administrative buildings rather than remotely located on the airport surface, do you feel your job performance would be affected?	___	___	___	___
6. Without changing the number of roof supports, if the five window supports were increased to fifteen, do you feel your job performance would be affected?	___	___	___	___

(Continued)

	POSSIBLY MUCH BETTER	NO DIFFERENCE	POSSIBLY MUCH WORSE	CAN'T SAY
7. Do you favor eliminating an outside catwalk and switching to a window cleaning system using a man in a self-propelled car?	___	___	___	___

PART VI
General Comments

If you have any opinions or comments about visual features on workspace layout in tower cabs which the questionnaire has not adequately covered, please write them in here:

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